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**CIVIL ENGINEERS**



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**BOSTON SOCIETY OF CIVIL ENGINEERS**FOUNDED 1848

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**PROCEEDINGS**

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**PAPER IN THIS NUMBER.****Report of the Committee on Run-Off.**

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Contributors are hereby notified that proof will not be submitted to them for examination unless requested before the 10th of the month preceding the month of publication.

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**MINUTES OF MEETING.**

BOSTON, October 4, 1922. — The Sanitary Section of the Boston Society of Civil Engineers held a meeting this evening in the Society Rooms, Tremont Temple. The meeting was called to order at 7.45 P. M. by the Chairman, Arthur D. Weston.

In the absence of the Clerk, John P. Wentworth was elected Clerk pro tem.

The Chairman announced that the Executive Committee had elected Frank L. Flood to membership.

The Chairman introduced Prof. George C. Whipple, who presented a paper on "Mosquito Control in Massachusetts." The paper was followed by a description of the different species of mosquitoes by Prof. C. T. Brues, of Harvard University. The subject was discussed by Messrs. Chase, Porter, Marston and Dorr.



A moving picture film entitled "The Mosquito and the Flea" was shown.

On motion of Mr. Marston, it was voted: That the Executive Committee be requested to direct a communication to the Affiliation Council with the request that a Committee be appointed to consider the question of mosquito extermination and to coöperate with the Anti-Mosquito League.

On motion of Mr. Fales, a rising vote of thanks was given to Prof. Whipple and Prof. Brues for their courtesy in speaking to the Section.

Members and guests present 51. The meeting adjourned at 9.45 P. M.

JOHN P. WENTWORTH, *Clerk pro tem.*

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### APPLICATIONS FOR MEMBERSHIP.

[October 15, 1922.]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of twenty (20) days from the date given.

CHASE, EDWARD SHERMAN, West Newton, Mass. (Age 38, b. Merrimac, Mass.) Graduate of Mass. Inst. Tech. in Sanitary Engineering, 1907. Was a rodman during summer of 1905; topographic draftsman in summer of 1906; chemist, bacteriologist 1908-9; chemist in charge, sewerage purification, 1909-13; assistant engineer, state department of health, 1913-20; sanitary engineer, 1920 to date. Refers to H. P. Eddy, F. A. Marston, L. Metcalf, A. L. Shaw, J. P. Wentworth and A. D. Weston.

FESSENDEN, HOWARD PIKE, Newton Centre, Mass. (Age 31, b. Newton Centre, Mass.) Graduate of Massachusetts Institute of Technology in 1913. Has been draftsman, designer, squad chief, assistant engineer and junior engineer with Stone & Webster, Inc., from 1913 to date. Refers to L. S. Cowles, E. P. Lane, J. H. Manning, C. E. Nichols, D. M. Wood.

GLYNN, THOMAS P., Boston, Mass. (Age 50, b. Boston, Mass.) Educated in the Boston English High School and Northeastern College School of Law. Learned the trade of brick and stone masonry and served as foremen, superintendent, estimator and general contractor on all kinds of building construction. He has held the position of sewer inspector, schoolhouse inspector, and for seven years was chief of department of alterations and repairs in schoolhouse department. Is now chairman of the Schoolhouse Commissioners of the City of Boston. Refers to J. E. Carty, G. W. Dakin, E. S. Dorr, C. S. Drake, J. E. L. Monaghan and H. L. Patterson.

MORELAND, EDWARD L., Brookline, Mass. (Age 37, b. Lexington, Va.) Graduate of Johns Hopkins University, Mathematical-Physical course; and of Massachusetts Institute of Technology, Electrical Engineering course. He is a Fellow of the American Institute of Electrical Engineers, a member of American Society of Mechanical Engineers. Was assistant engineer with D. C. and Wm. B. Jackson, 1908-1912; manager Boston office 1912-1915; partner 1916-1918; Captain and Major, Engineers Corps, U. S. Army, 1918-1919; and partner and manager of Jackson & Moreland 1919 to date. Refers to F. H. Fay, C. R. Gow, F. M. Gunby and D. C. Jackson.

THORON, BENJAMIN WARDER, Danvers, Mass. (Age 25, b. Washington, D. C.) Graduated from Harvard College 1918, Mass. Inst. Tech., in civil engineering, 1922. Is a draftsman in the office of Fay, Spofford & Thorndike. Refers to C. R. Berry, E. Harsch, R. W. Horne, H. A. Gray, W. F. Pike, C. M. Spofford.

WINSLOW, EARL HOLDEN, Norwood, Mass. (Age 24, b. Westboro, Mass.) Graduate of Worcester Polytechnic Institute with degree of B. S. in chemistry in June, 1921. Was in the army from July 27 to Dec. 20, 1918. Most of 1919 was employed in the laboratory of the General Electric Co. at the Pittsfield Works; where he was assistant in metallurgical research; during the summer of 1920 was employed at the North Works of the American Steel & Wire Co., Worcester, as a wire cutter and gager; in June, 1921 entered the employ of Metcalf & Eddy as a sanitary engineer, and is still in their employ. Refers to S. E. Coburn, H. P. Eddy, A. L. Fales, A. L. Maddox and J. P. Wentworth.



## LIST OF MEMBERS.

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## DEATH.

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| MORSE, WILLIAM F. .... | September. 15, 1922 |
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## LIBRARY NOTES.

## RECENT ADDITIONS TO THE LIBRARY.

## U. S. Government Reports.

Bureau of Civil Service. Report to Governor-General of Philippine Islands. 1921.

Census of United States. Vol. 3, Vol. 6, Parts 1, 2 and 3. 1920.

Census of United States. (Massachusetts, Manufactures.) 1919.

Water Supply Papers, Nos. 463 and 478.

## State Reports.

Massachusetts. Industrial Review, No. 8.

### **Municipal Reports.**

Brockton, Mass. Annual Report Water Commissioners. 1921.

Erie, Pa., Annual Report Water Works. 1921.

Marlboro, Mass. Annual Report Water and Sewage Commissioners. 1921.

Newton, Mass. Annual Report City Engineer. 1920 and 1921.

New York, N. Y. Annual Report Board of Water Supply. 1921.

New York, N. Y. Annual Report President Borough of Manhattan. 1921.

North Andover, Mass. Annual Report Board of Public Works. 1921.

### **Miscellaneous.**

Report on Structural Materials along St. Lawrence River between Prescott, Ont., and Lachine, Quebec. Dept. of Mines Canada.

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BOSTON SOCIETY OF CIVIL ENGINEERS.

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REPORT  
OF THE  
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---

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## REPORT OF THE COMMITTEE ON RUN-OFF.

[The full report of the Committee included duration tables and complete run-off records for twelve stations.\* These tables were not printed in this report on account of the expense, but a copy will be available at the library of the BOSTON SOCIETY OF CIVIL ENGINEERS.]

### HISTORICAL.

THE Committee was appointed under the following resolution:

*"Resolved;* That the president be and hereby is authorized to appoint a committee to collect, compile, analyze and report upon the best figures of run-off in New England, which are available for water power purposes."

This resolution was suggested in a letter written by the Chairman to Richard A. Hale, November 22, 1916, then President of the Society.

Mr. Hale made the following original appointments to the Committee:

Arthur T. Safford, Chairman, Proprietors of Locks and Canals, Lowell, Mass.

Harold S. Boardman, University of Maine, Orono, Maine.

X. Henry Goodnough, State Department of Health, Boston, Mass.

Richard A. Hale, Essex Company, Lawrence, Mass.

Charles H. Pierce, U. S. Geological Survey, Boston, Mass.

George E. Russell, Mass. Institute of Technology, Cambridge, Mass.

Charles W. Sherman, Metcalf & Eddy, Boston, Mass.

Herbert A. Moody, Turners Falls Co., Turners Falls, Mass.

W. Frank Uhl, Charles T. Main, Boston, Mass.

Joseph F. Wilbur, French & Hubbard, Boston, Mass.

Dana M. Wood, Stone & Webster, Inc., Boston, Mass.

Messrs. Russell, Moody and Wilbur resigned after attending several meetings of the Committee on account of business engagements; and their places were filled by the appointment of:

---

\* See footnote on page 167



A. C. Eaton, New England Power Co., Worcester, Mass.  
Walter H. Sawyer, Union Water Power Co., Lewiston, Maine.  
Frank E. Winsor, Providence Water Board, Providence, R.I.  
S. Stanley Kent, Proprietors of Locks and Canals, Lowell, Mass.

The object of the work being the collection, compilation and analysis of run-off figures for water power purposes, the Committee was made to include representatives of the engineering schools, of the Water Resources Branch of the U. S. Geological Survey, and of companies and engineering firms interested in water power.

Beginning with January 24, 1917, the Committee met frequently up to January, 1921. There was some interruption in the meetings during the early part of the war and the attendance at times has been small, due to a multitude of other engagements; but the Committee has met 33 times in all; there have been 16 meetings of sub-committees and in addition a great deal of work done through correspondence and individual calls by different members of the Committee.

There have been published by the New England Water Works Association two papers or reports of committees, with basic data to some extent like that which forms the subject of this report; and one paper on rainfall. These reports are as follows:

Yield of Drainage Areas (Report of Committee of N.E. W.W.A.) Vol. XXVIII (1914) page 397.

This report was written from the water works standpoint with particular reference to the dry period from 1908 to 1911. During this period the yield for 7 water works streams, most of them in New England and less than 100 sq. mi. in area, was 1.44 second feet per square mile. The average for the 10 years from 1911 to 1920 for the same stations was 1.66 second feet per square mile.

Data relative to awards for water and water power diversion (Report of Committee of N.E.W.W.A.) Vol. XXIV (1910) page 1.

This Committee published as basic data the average flow of the Sudbury River, 1.617 second feet per square mile in the

34 years from 1875-1908; the Nashua River, 1.829 second feet per square mile in the 12 years from 1897-1908; and the Croton River, 1.73 second feet per square mile for the 41 year period from 1868 to 1908. The averages for the same stations for the complete periods to 1920 are 1.52 second feet per square mile for the Sudbury; 1.67 for the Nashua and 1.665 for the Croton. The report consisted chiefly of a large amount of data relating to awards that have been made for damages resulting from the diversion of water.

Rainfall in New England, N. H. Goodnough, *Journal of N.E.W.W.A.* Vol. 29, (1915) page 237.

This paper covers admirably the source of run-off; and the supplementary report, bringing the figures for New England through 1920, was published in the *Journal of N.E.W.W.A.*, Vol. 35, No. 3 (September 1921).

The diagram in Mr. Goodnough's first paper showing progressive average rainfall in eastern Massachusetts 1749-1913 has been brought up to include 1920 and is reproduced in this report. (See Fig. 5.)

The earliest records of run-off in New England, most of them kept by water works or water power companies, are now available for nearly 50 years, but they are few in number. For the lack of more records they have been used by engineers over and over in design of water works, diversion cases and water power developments. Fortunately the care with which these early records were taken has made them reliable.

The scarcity of records outside of a few streams, most of them small ones, and the expense of getting an accurate record by water power companies led to the simpler methods and more comprehensive investigations of the U. S. Geological Survey beginning about twenty years ago. In New England many new stations have been installed and maintained for a longer or shorter period. The older water works and water power stations through the Survey bulletins have had the benefit of comparative records and special monographs on methods of making measurements and recording and publishing stream flow records. In addition records and papers on run-off and subsequent discussions by members of the engineering societies have helped to

make the records more available and the methods better understood. Even now, however, thoroughly reliable records, well scattered over New England, from which can be accurately determined the effects of cutting and subsequent growth of timber, the per cent. of precipitation collected in run-off, the point to which it is economical to spend millions perhaps in the development of water power on a given stream, the value of a given water power if taken away for water supply purposes, are not available. All of these problems require accurate long term records and more of them. More money should be appropriated for the U. S. Geological Survey work in New England, more precipitation stations installed, particularly in high altitudes, state maps should be completed, and water power operators and engineers should be willing to advise owners of water power that money for these purposes is well spent and necessary.

Within a very few years the main difficulties which heretofore have threatened the accuracy of run-off records—the effect of ice in winter, of daily fluctuations due to the use of pondage above the station, of backwater below the station, of shifting control, together with small errors which may be expected from types of instruments used, methods of handling and the human element in observers—have been more fully overcome than ever before; and, with money to do with and the more complete use of automatic gages and coöperation by owners of water power, it is hoped the next 10 years will see a tremendous improvement in the number and accuracy of the New England stations.

The Committee on Run-off has already published a Progress Report in the JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS, November, 1918. Most of the material was in the nature of papers by members of the Committee treating of matters which had been the subject of discussion at committee meetings. There are available several other valuable papers on other subjects which have been written by members of the Committee. These should appear in forthcoming JOURNALS of the Society.

## SCOPE OF REPORT.

The full report of the Committee includes:

- (a) A list of most of the published run-off records for New England with an index of where they can be found.\*
- (b) A grading or rating of these stations according to their relative accuracy.
- (c) The compilation in full of 12 of the best and most representative of the longer term stations.†
- (d) Representative hydrographs and duration curves.
- (e) Duration tables for a large number of stations.\*
- (f) A map of New England showing the extent of the principal drainage areas, the location of the gaging stations and a selected number of rainfall stations with figures of the mean annual precipitation.
- (g) A glossary of terms.
- (h) A bibliography.\*

The glossary of terms given with this report contains only the most important of them, and it is hoped by the Committee that new terms will be not added without very good reasons.

The Committee has, we believe, made a start towards bringing together run-off records collected primarily for water works and water power purposes and hopes this may be continued, as eventually engineers will require all the best records whether on small or large rivers, whether maintained for water works or for water power purposes.

The following is a complete list of all papers submitted to the Committee for discussion, most of them by members of the Committee:

"Glossary of Terms," by D. M. Wood.

"The Use of the Current Meter in Stream Gaging," by C. H. Pierce.

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\* Not published in this report.

† These records not published in this report were as follows: St. John R. at Van Buren Me., 1908-1920; Penobscot R. at Westfield, Me., 1901-1920; Mattawamkeag R. at Mattawamkeag, Me., 1902-1920; Androscoggin R. at Rumford Falls, Me., 1892-1920; Presumpscot R. at Sebago Lake, Me., 1887-1920; Merrimack R. at Lawrence, Mass., 1880-1920; South Branch Nashua R. at Clinton, Mass., 1881-1910; Souhegan R. at Merrimack, N. H., 1909-1920; Connecticut R. at Orford, N. H., 1900-1920; Deerfield R. at Charlemon and Shelburne Falls, Mass., 1907-1920; Housatonic R. at Falls Village, Conn., 1912-1920; Lamoille R. at Cady's Falls, Vt., 1913-1920.



- "0.2 and 0.8 Method of Current Meter Measurement in Power Canals," by A. T. Safford.
- "Precipitation, Evaporation and Run-off," by A. T. Safford.
- "The Effects of Ice on River Discharge," by C. H. Pierce.
- "Methods to be Used in Compilation of Data," by C. H. Pierce and D. M. Wood.
- "Snowfall," by H. S. Boardman.
- "Use of the Venturi Meter for Run-off Measurements," by Clemens Herschel.
- "The Human Element in Gage Reading," by C. W. Sherman.
- "Flood Measurements," by D. M. Wood.
- "Inspection and Tests of Run-off Records," by C. H. Pierce.
- "Classification—Factors Affecting Run-off Records," by D. M. Wood.

Suggestions and criticisms of the work of the Committee or answers to questionnaires have also been received on questions submitted by the Committee from the following engineers to whom the thanks of the committee are extended.

|                |                    |               |
|----------------|--------------------|---------------|
| A. S. Addison  | Desmond Fitzgerald | C. A. Mixer   |
| M. G. Barnes   | J. R. Freeman      | Dwight Porter |
| H. K. Barrows  | F. L. Fuller       | C. M. Saville |
| P. L. Bean     | G. F. Hardy        | J. W. Smith   |
| Clinton Bogert | Clemens Herschel   | Earl Stafford |
| H. F. Bryant   | R. E. Horton       | F. P. Stearns |
| C. E. Chandler | I. E. Houk         | J. L. Tighe   |
| H. L. Coburn   | H. J. Hughes       | H. M. Turner  |
| A. S. Crane    | C. T. Main         | J. F. Vaughan |
| E. A. Ekern    | F. H. Mason        | A. E. Winslow |
| H. S. Ferguson | I. W. McConnell    | C. O. Wister  |

The Committees sought to determine the preference of hydraulic engineers in regard to the publication of run-off records, whether by calendar years, or on a climatic year basis as used by the U. S. Geological Survey. The majority of replies received somewhat favored the calendar year. However, in view of the fact that most of the records used in water power practice are published in the Water Supply Papers of the U. S. Geological Survey and are on a climatic year basis, and that future records and duration tables will become available in that form, it seemed

best to the Committee to adopt this method although the Committee regrets the necessity for this change from the calendar year.

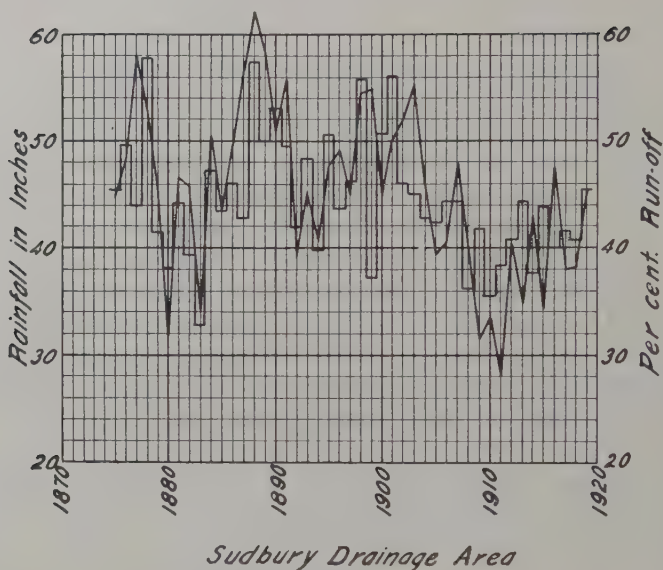
With the hope of helping to answer some of the open questions concerning the amount and distribution of run-off in New England the Committee has gathered data for a number of streams for which the annual run-off in second feet per square mile is given by way of summary in Appendix A, page 182.

The long term records show that the ten year period from 1911 to 1920 is a very valuable one for run-off records and fortunately many new and good records have been obtained during this period. The period is one of from average to very low rainfall and remarkable in every way.

The principal questions concerning run-off which have been asked of engineers during the past 50 years and about which a great many controversies and discussions have raged and will continue to rage, are:

#### RAINFALL AND RUN-OFF.

The effect of increased amounts of rainfall to increase the per cent. of run-off. The results clearly indicate that broadly speaking an increase of rainfall does materially increase the per cent. of run-off. On the Sudbury and Wachusett watersheds 40 in. of rainfall corresponds to about the same per cent. of rainfall collected; while 60 in. of rainfall increases this per cent. of collection by 50 per cent. The drainage area above the Merrimack River at Lawrence, Mass., shows a similar tendency with a somewhat higher ratio of run-off to rainfall, which may be partly due to lack of high altitude rainfall stations in that basin. Individual years show marked discrepancies, due probably to differences in the amount of ground storage carried over from year to year and to differences in the distribution of the rainfall during the year and the conditions under which the precipitation took place, but the general trend is distinctly as stated above. A diagram (Fig. 1) of the rainfall and run-off of the Sudbury and Wachusett watersheds of the Metropolitan Water Supply is submitted to illustrate this point.



Rainfall in  
inches shown  
thus:  $\angle$   
Per cent.  
run-off shown  
thus:  $\text{N}$

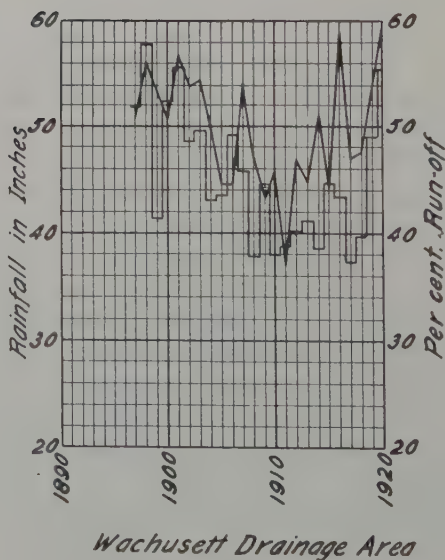


FIG. 1 — ANNUAL RAINFALL AND PER CENT. RUN-OFF.

## COMPARISONS BETWEEN RUN-OFF RECORDS.

The Committee deems it expedient to call attention to two interesting methods of making comparisons between run-off records, because they are not in common use and do bring out important facts.

One method has been suggested (Stone & Webster JOURNAL for February 1917) by which the relative distribution of run-off at two stations may be studied, and which sometimes indicates an unsuspected similarity between the run-offs at the two points.

This method is illustrated by Figs. 2 and 3 of this report, which furnish a comparison of the run-off of the Connecticut River at Holyoke and at Orford, with the Merrimack River at Lawrence for the period of years common to the records. The method consists in taking off from the duration curves of flow for each station the flows corresponding to say each 5 per cent. increment of time on the "per cent. of time" scale, and computing their ratio to the respective long term average flow for each station. These results are then plotted in the form of curves, as illustrated. The vertical scale is, therefore, a relative scale (it can be a "per cent. of average flow" scale if desired) instead of an absolute scale of second feet per square mile.

This method results in a comparison of the relative distribution of run-off regardless of the size of drainage area or the disparity between average flows at the stations. In the cases shown there is a surprising similarity in the relative distribution in spite of the differences in drainage areas and average unit run-offs.

As further indicating the variations in annual run-off to be expected on the same stream at different points of the drainage area and hence indicating the value of the foregoing method of comparison, Fig. 4 is attached, which gives a second method of comparison and one which indicates clearly the variation in average long term run-off on the Connecticut River. This curve illustrates the fact generally found on all New England streams, — that average run-off increases materially as the size of drainage area decreases or as the station is moved from the mouth toward the source, from low to high altitudes. This fact can readily be shown graphically as in the instance given.



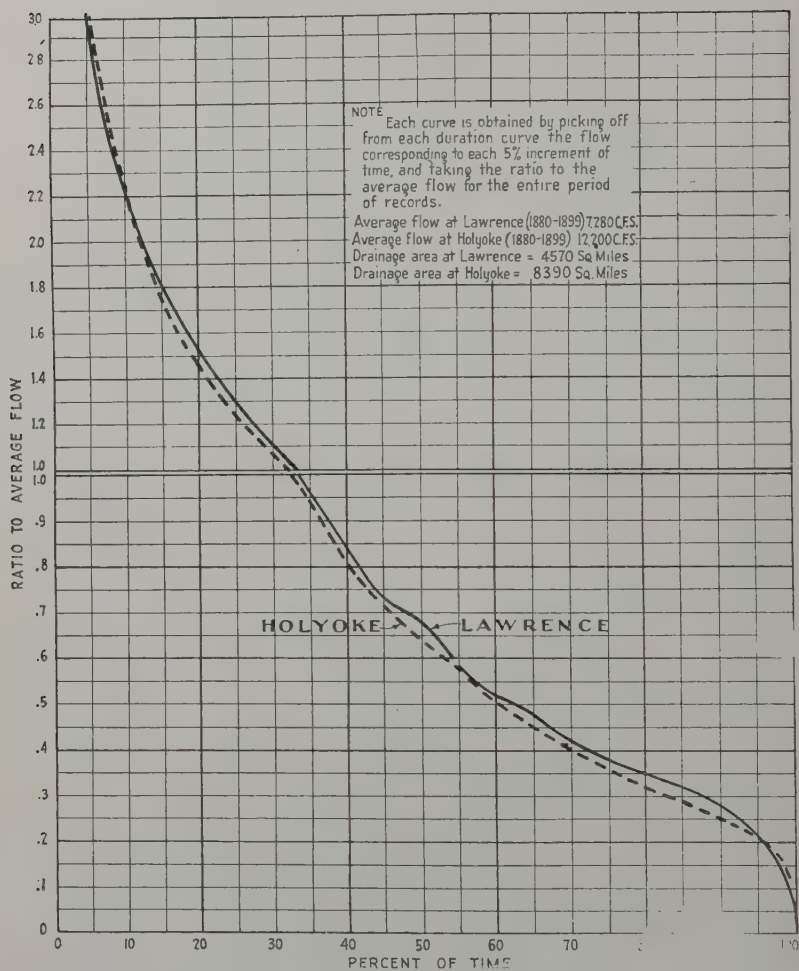


FIG. 2 — COMPARISON OF RUN OFF.

Connecticut and Merrimack Rivers at Holyoke and Lawrence.  
 Period — October, 1880 to September, 1899.

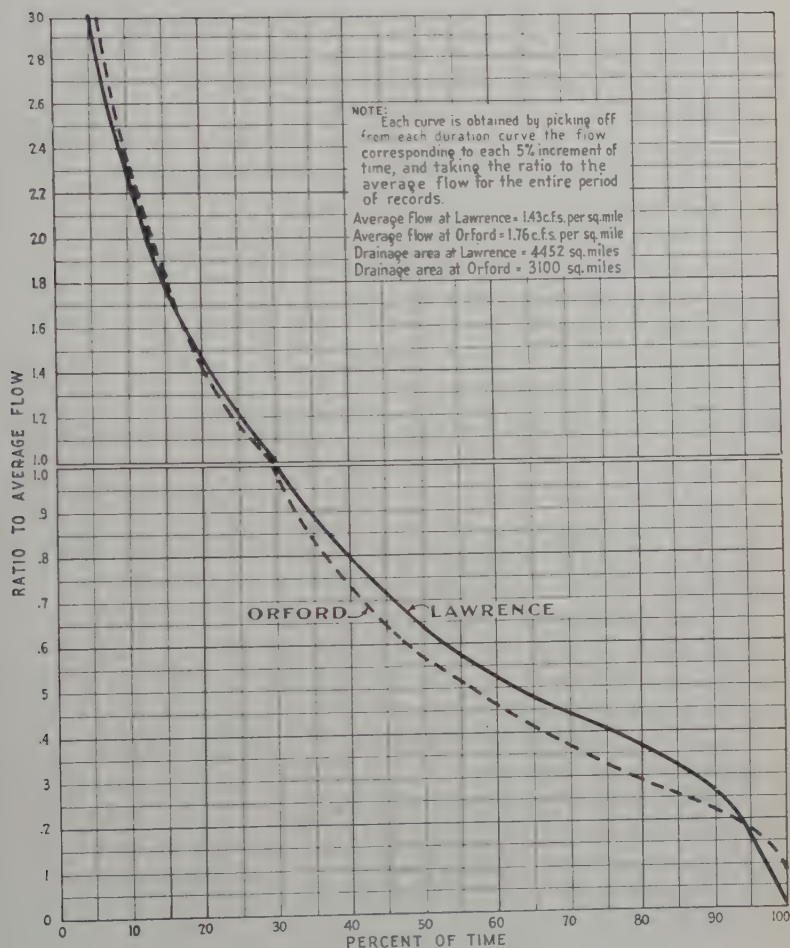


FIG. 3 — COMPARISON OF RUN-OFF  
 Connecticut and Merrimack Rivers at Orford and Lawrence.  
 Period — October, 1900 to September, 1920.

This second method indicates clearly the important point that the often used theory of applying the same unit run-offs at one station to another locality some distance away in the same watershed is wrong, and if employed is likely to lead to erroneous conclusions. Similarly, much more care is necessary in ascertaining relative conditions if the unit run-off in one basin are to be applied in contiguous basins.

Variations and apparent discrepancies in records for stations on the same river can usually be explained by differences in rainfall on the drainage areas above the stations; but variations or defects in records at one station due to pondage, ice, raising or lowering of flashboards, etc., can be explained only by an intimate knowledge of the operation of each station, by long continued observations and more of them in a day. Many of the best stations are not available for long term comparisons due to the absence of continuous winter records.

#### LARGE AND SMALL STREAMS.

The increase in unit run-off as the drainage area decreases indicated in the preceding paragraphs brings up the question of the effect of the size of the drainage area. Although the results are not conclusive, it appears that such increases are due chiefly to other causes than the size of the tributary drainage area. Such precipitation and stream flow records as are available support the statement that, other things being equal, run-off increases with altitude in New England. If this is true it follows that the unit run-off will increase as the source of a stream is approached. On the other hand tributary streams at low altitudes in the lower part of drainage basins frequently have a lower yield than the main river, thus proving that the size of drainage area is not the controlling factor. Six small streams with low altitude drainage areas in the 10 years from 1911 to 1920 averaged 1.44 second feet per square mile while for the same period six large streams averaged 1.75 second feet per square mile.

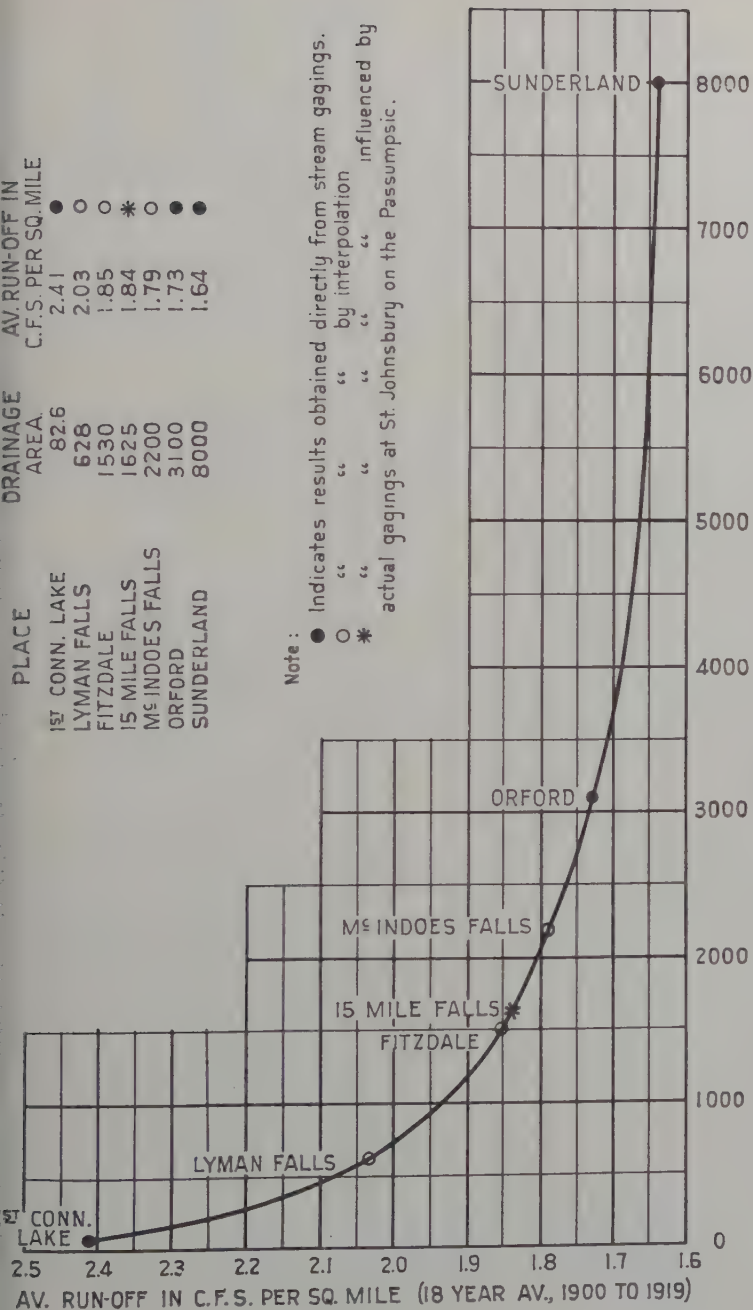


FIG. 4 — RELATION OF RUN-OFF TO DRAINAGE AREA.  
Hydraulic Studies of Connecticut River.

## PRECIPITATION RECORDS.

The progressive average rainfall, particularly for eastern Massachusetts in the 18th century, shows relatively but little greater differences in the precipitation than in the 19th. What long term records of run-off we have appear to bear out the fact that there are no greater differences in the flow than exist because of the differences in rainfall. The diagram Plate XXIII in the paper by X. H. Goodnough already referred to is given by way of illustration. (See Fig. 5.)

Precipitation stations, while numerous when shown on a map of New England, are located for the most part in the valleys. The number of high altitude stations should be much increased. One engineer has suggested a precipitation station in every township of 36 square miles.

The run-off in inches on the drainage area is a figure which should prove useful in many cases to water works and water power engineers using run-off records. The "per cent. of run-off" has little value where the precipitation of several thousand square miles is represented by one or two stations. The value of per cent. of run-off figures will be much increased when the precipitation stations fairly represent the drainage areas.

## SNOW COVER.

The snow cover at the end of each winter month becomes important on account of its possibilities for good or evil. The freshet is always the one menace to the engineer who tries to save money in the construction of coffer and masonry dams and other heavy structures across our great rivers; but the same snow may be converted into the best kind of insurance in the way of water storage. The Committee suggests that some standard form of snow record be adopted, and recommends that surveys be made and snow records be maintained as important.

## EVAPORATION.

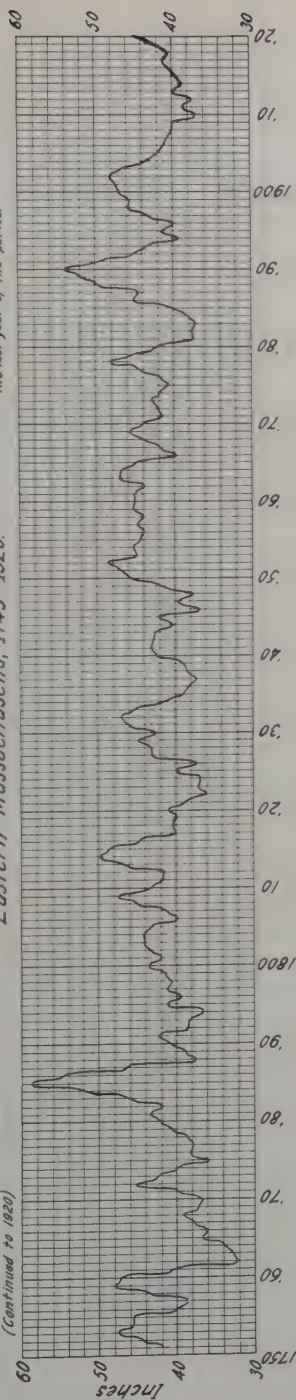
Very little new material on evaporation has been at the disposal of the Committee. Whatever we have may probably be taken as equivalent to the Chestnut Hill, Mass., records reduced



Taken from Journal of the New England  
Water Works Association, Sept. 1915, Plate XVIII.  
(Continued to 1920)

# Diagram Showing Progressive Average Rainfall in Eastern Massachusetts, 1749-1920.

Note: The progressive is made by plotting the  
successive averages of the rainfall for three  
year periods up to the date more representing  
the last year of the period.



## Diagram Showing Annual Run-off and Precipitation for Merrimack River Drainage Area

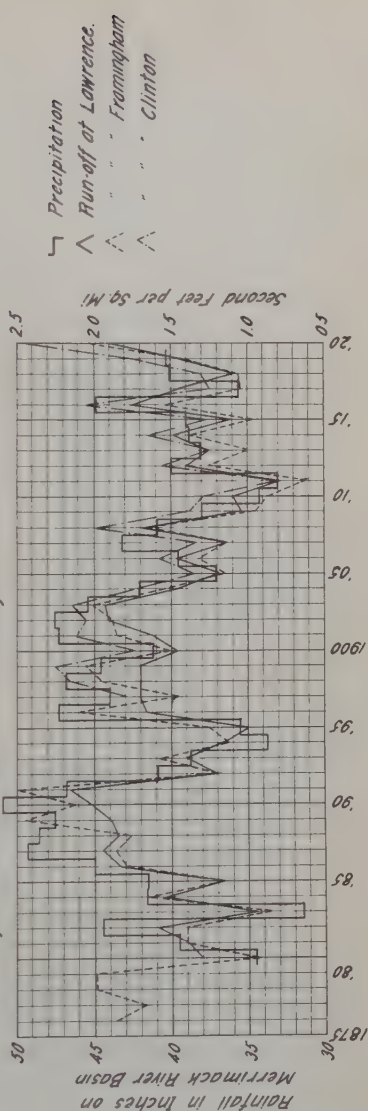


FIG. 5.

by an amount equal to about 1 in. of evaporation per month to 9 degrees Fahr. of temperature which of course refers only to a climate like that of New England. Tables of evaporation which apply to New England are offered as far as they are available.

TABLE 1.

EVAPORATION IN INCHES FROM WATER SURFACE AT CERTAIN LOCALITIES  
IN NEW ENGLAND AND NEW YORK, BY MONTHS

|                 | Chestnut<br>Hill,<br>Boston,<br>Mass.<br>In. | Maine,<br>Composite<br>Figures.<br>In. | Fall River,<br>Mass.<br>1899-1901<br>In. | Mt. Hope<br>Reservoir,<br>Rochester,<br>N. Y.<br>1891-1907*<br>In. |
|-----------------|----------------------------------------------|----------------------------------------|------------------------------------------|--------------------------------------------------------------------|
| January .....   | 0.96                                         | 0.70                                   | 1.24                                     | 0.75                                                               |
| February .....  | 1.05                                         | 0.70                                   | 1.10                                     | 0.79                                                               |
| March .....     | 1.70                                         | 1.10                                   | 2.05                                     | 1.44                                                               |
| April .....     | 2.97                                         | 1.60                                   | 3.27                                     | 2.61                                                               |
| May .....       | 4.46                                         | 2.10                                   | 4.59                                     | 3.74                                                               |
| June .....      | 5.54                                         | 2.80                                   | 6.13                                     | 4.52                                                               |
| July .....      | 5.98                                         | 4.32                                   | 5.91                                     | 5.14                                                               |
| August .....    | 5.50                                         | 5.00                                   | 4.73                                     | 4.86                                                               |
| September ..... | 4.12                                         | 3.32                                   | 4.08                                     | 3.86                                                               |
| October .....   | 3.16                                         | 2.20                                   | 2.73                                     | 2.74                                                               |
| November .....  | 2.25                                         | 1.30                                   | 1.66                                     | 1.52                                                               |
| December .....  | 1.51                                         | 0.70                                   | 1.23                                     | 1.16                                                               |
| The Year .....  | 39.20                                        | 25.84                                  | 38.72                                    | 33.13                                                              |

## MEASUREMENTS.

Controversies over methods of measurement, average velocity, types of current meters and the many and varied steps which go to make up a rating curve and its consequent use, should no longer exist. Engineers have agreed that for general use the current meter is the quickest and best method of measuring water running through a given cross section. When properly used and the velocity through the entire channel covered in one way or another, the rest is usually a matter of mathematics. The human element, which is such a very important element in obtaining accuracy, can be kept up to the mark only by con-

\* Records for July, Aug. Sept. and Oct. began in 1891, for May and June in 1892, for April in 1894, for Nov. and Dec. in 1895 and for Jan., Feb., and Mar. in 1896.

stant supervision on the part of some central authority like the U. S. Geological Survey.

The maximum and minimum flows, important as they are for purposes of rating a station and study of the records, are rarely obtainable because of the difficulty of knowing when to anticipate these conditions; and of making measurements at times of freshets and droughts.

For water wheel tests and measurements which appear to warrant the large expense of getting ready special apparatus, the weir, the Venturi meter, the chemical method and many others will be gradually standardized for use.

Many water power station records require a careful rating of the dam and flashboards. With many of our rivers 50 per cent. of the total flow of the year goes by the station in the form of waste. It is probable that the largest element of uncertainty and one which oftentimes rules out a station record is the absolute lack of intelligent coefficients covering the waste over dams and through gates.

Experiments on a large scale and with actual structures and velocities approaching them should be made and these dams, flashboards and gates should be rated with a fair degree of accuracy. Too much time has been spent upon model sections and orifices.

#### EFFECT OF PONDAGE.

The pondage of water in many of our streams has heretofore been responsible for a great many relatively high figures of run-off. The "concentration factor" or ratio of the use of water during working hours to the 24 hour flow may vary from 1 to nearly 3 where the water is ponded as it is at Lowell or Lawrence. The 24 hour flow at such a point is usually difficult to estimate unless special arrangements are made to get the average flow. This is also true of many stations on small streams where the effect of pondage above, though small, may still be enough to make valueless the records of run-off of these streams. These difficulties are now generally overcome by the use of automatic water stage recorders or by more frequent readings.

## WINTER RECORDS.

Many of the winter records which have been obtained in the past under ice conditions are viewed with suspicion and many otherwise good stations have been defective in this respect. The Committee believes that the method \* of correcting the gage heights for backwater produced by ice, the amount of which can only be determined by frequent winter discharge measurements, represents a distinct advance in the science of stream gaging under ice conditions and that the winter records have been much improved since about 1915, when this method came into general use. A diagram (Fig. 6) is given as an example of the application of this method. A gaging station at which a complete ice cover remains unbroken throughout the winter will give the best results by this method. The presence of anchor ice and the unstable conditions existing during the formation or disappearance of the ice cover make for uncertainty and during such periods accurate records can only be obtained by means of frequent discharge measurements.

## HYDROGRAPHS AND DURATION CURVES.

The hydrograph may be considered a desirable preliminary step to a study of run-off records and is recommended by the Committee.

The duration curve or table has been selected as one of the best means of showing the record of a given river; but the Committee has found that yearly duration curves or tables are much more comprehensive and are less misleading than an average. In this connection a study of five year periods or a series of dry and wet years is valuable.

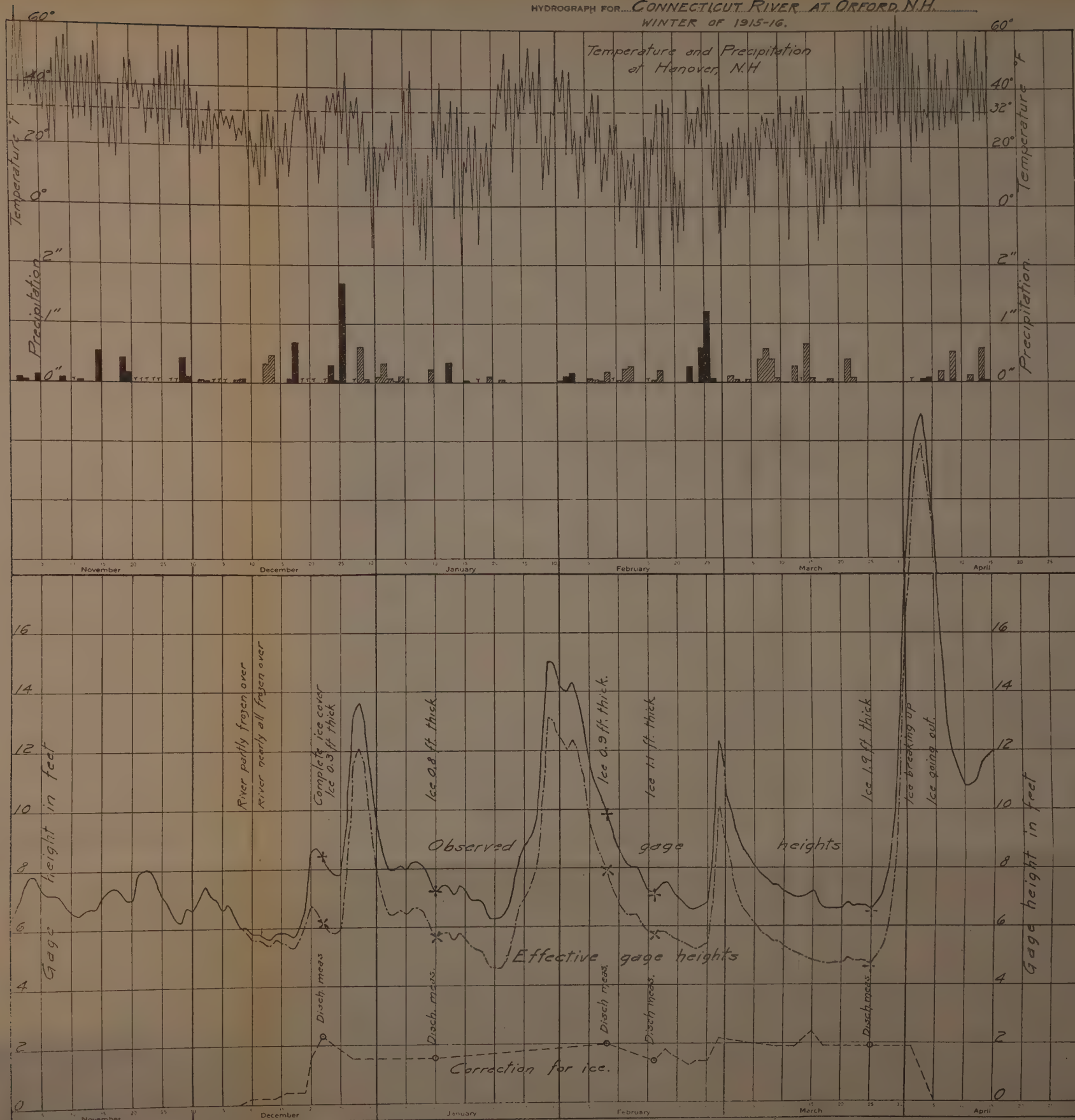
## EFFECT OF DEFORESTATION.

The effect of cutting the forests and of subsequent growth upon the flow of streams is not clear, and the question has for many years been under discussion. The work of this Committee has not included a study of this problem as it alone might well

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\* See paper on "The Effects of Ice on River Discharge." in the preliminary report of this Committee, JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS, November 1918.





Plotted by *[Signature]* Checked by *H.T.* Date

SHOWING METHOD OF WORKING UP WINTER RECORDS.





involve an intensive investigation. Very broadly speaking, it may be said that results of a conclusive nature can only be obtained by an intensive investigation, in which preferably two small adjacent areas, one forested and the other deforested, are compared. These areas must, so far as practicable, be so located with reference to prevailing storms, topography, geology and all other contributing factors except that of forestation, that any detectable difference in run-off may fairly be attributed to the relative forestation. Theoretically, large areas might be studied, but the lack of reliable long term run-off records covering different degrees of forestation makes any deductions uncertain.

The results from the 12 stations studied by this Committee bear out in a general way the foregoing statements; but there should be an additional ten year unbroken record for many of these stations before definite conclusions can be drawn.

#### IMPORTANCE OF RECORDS.

The interest which engineers and members of the New England Water Works Association have in run-off records should be merged with the interest of water power engineers. The use of measurements on streams of considerable size is becoming more and more important to the public, engineers and water power owners with the increasing value of water power. On many streams the absolute minimum for steam, washing and process purposes has a value way in excess of its value for power. Equipment is now being installed in many cases double that of ten years ago; and while some of it lies idle for a part of the year, yet these larger installations reduce the coal bill during many months. A merely conservative small figure no longer interests the engineer, but rather figures more favorable to the use of water power. Waste waters and their possibilities are being studied for water storage and the flow available for each tributary stream must be known in advance.

Every water power owner ought to agree to maintain a first class station at his own plant if possible; or if conditions will not allow this, ought to be willing to share with others the expense of maintaining a first class station on his river, including precipitation stations, particularly high altitude ones.

The Committee submits its work with the hope that all of the material submitted may be of value to the Society and a large part if not all of the report may be published.

Respectfully submitted,

ARTHUR T. SAFFORD, *Chairman*

C. H. PIERCE, *Secretary*

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MARCH 16, 1921.

## APPENDIX A.

APPENDIX A.  
JOURNAL BOSTON SOCIETY  
OF CIVIL ENGINEERS.  
OCTOBER, 1922.

COMPARISON OF NEW ENGLAND RUN-OFF FIGURES.  
NOT NECESSARILY ALL OF THE BEST RECORDS BUT INCLUDING MOST OF THE OLDER ONES.  
Mean annual Run-off in second feet per square mile.

REPORT OF COMMITTEE  
ON RUN-OFF

| Year              | St. John River at Van Buren, Me. 8270 sq. mi. | Penobscot River at W. Enfield, Me. 6660 sq. mi. | Mattawamkeag River at Mattawamkeag 1500 sq. mi. | Kennebec River at Waterville, Me. 4270 sq. mi. | Androscoggin R. at Rumford Falls, Me. 2090 sq. mi. | Presumpscot R. at Sebago Lake, Me. 436 sq. mi. | Merrimack River at Lawrence, Mass. 4552 sq. mi. | METROPOLITAN W. W. MASS. |      |      | Souhegan River at Merrimack, N. H. 168 sq. mi. | Pawtucket, R. I. Abbott Run 26.94 sq. mi. | Pawtuxet R. at Fiskeville, R. I. 101.8 sq. mi. | CONNECTICUT RIVER AT |      |      | Deerfield River at Charlemont and Shelburne Falls, Mass. 362 and 501 sq. mi. | Westfield, Little River 48 sq. mi. | Holyoke W. W., Mass. Manhan River 13 sq. mi. | Housatonic River at Falls Village, Conn. 644 sq. mi. | Lamoille River at Cady's Falls, Vt. 280 sq. mi. | Croton River, N. Y. Water Supply 375 sq. mi. | New York W. Supply Esopus Creek 239 and 192 sq. mi. |
|-------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------------------|-------------------------------------------------|--------------------------|------|------|------------------------------------------------|-------------------------------------------|------------------------------------------------|----------------------|------|------|------------------------------------------------------------------------------|------------------------------------|----------------------------------------------|------------------------------------------------------|-------------------------------------------------|----------------------------------------------|-----------------------------------------------------|
|                   | (1)                                           | (2)                                             | (3)                                             | (4)                                            | (5)                                                | (6)                                            | (7)                                             | (8)                      | (9)  | (10) | (11)                                           | (12)                                      | (13)                                           | (14)                 | (15) | (16) | (17)                                                                         | (18)                               | (19)                                         | (20)                                                 | (21)                                            | (22)                                         | (23)                                                |
| 1871.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | ..                       | ..   | 1.05 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.34                                         | ..                                                  |
| 1872.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | ..                       | ..   | 1.11 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.16                                         | ..                                                  |
| 1873.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | ..                       | ..   | 1.87 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.73                                         | ..                                                  |
| 1874.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | ..                       | ..   | 1.77 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.70                                         | ..                                                  |
| 1875.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | ..                       | ..   | 1.09 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.72                                         | ..                                                  |
| 1876.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | 1.86                     | ..   | 1.49 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.45                                         | ..                                                  |
| 1877.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | 1.67                     | ..   | 1.51 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.40                                         | ..                                                  |
| 1878.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | 1.98                     | ..   | 1.86 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.89                                         | ..                                                  |
| 1879.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | ..                                              | 1.99                     | ..   | 1.64 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.36                                         | ..                                                  |
| 1880.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.30                                            | 0.93                     | ..   | .79  | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 0.86                                         | ..                                                  |
| Ten year average  | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.30                                            | 1.69                     | ..   | 1.42 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.46                                         | ..                                                  |
| 1881.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.39                                            | 1.40                     | ..   | 1.14 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 0.99 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.31                                         | ..                                                  |
| 1882.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.60                                            | 1.40                     | ..   | 1.12 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.39 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.68                                         | ..                                                  |
| 1883.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 0.94                                            | 0.86                     | ..   | .76  | ..                                             | ..                                        | ..                                             | ..                   | ..   | 0.96 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 0.91                                         | ..                                                  |
| 1884.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.54                                            | 1.67                     | ..   | 1.34 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.39 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.67                                         | ..                                                  |
| 1885.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.16                                            | 1.20                     | ..   | 1.02 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.30 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.22                                         | ..                                                  |
| 1886.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.83                                            | 1.79                     | ..   | 1.67 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.45 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.38                                         | ..                                                  |
| 1887.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | ..                                             | 1.95                                            | 1.87                     | ..   | 1.84 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.78 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.86                                         | ..                                                  |
| 1888.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.93                                           | 1.85                                            | 1.77                     | ..   | 1.53 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.70 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 2.46                                         | ..                                                  |
| 1889.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.97                                           | 1.89                                            | 2.45                     | ..   | 2.36 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.75 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 2.19                                         | ..                                                  |
| 1890.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.92                                           | 2.02                                            | 2.11                     | ..   | 1.89 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.98 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.80                                         | ..                                                  |
| Ten year average  | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.94                                           | 1.62                                            | 1.65                     | ..   | 1.47 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.47 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.65                                         | ..                                                  |
| 1891.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 2.01                                           | 2.14                                            | 2.48                     | ..   | 2.67 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.76 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.63                                         | ..                                                  |
| 1892.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.55                                           | 1.20                                            | 1.18                     | ..   | 1.13 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.38 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.21                                         | ..                                                  |
| 1893.....         | ..                                            | ..                                              | ..                                              | ..                                             | ..                                                 | 1.34                                           | 1.41                                            | 1.57                     | ..   | 1.21 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.38 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 2.04                                         | ..                                                  |
| 1894.....         | ..                                            | ..                                              | ..                                              | 0.95                                           | ..                                                 | 1.47                                           | 1.16                                            | 1.12                     | ..   | 1.00 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.00 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.44                                         | ..                                                  |
| 1895.....         | ..                                            | ..                                              | ..                                              | 1.22                                           | ..                                                 | 1.32                                           | 1.00                                            | 1.26                     | ..   | 1.11 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.04 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.09                                         | ..                                                  |
| 1896.....         | ..                                            | ..                                              | ..                                              | 1.88                                           | ..                                                 | 1.53                                           | 1.67                                            | 2.09                     | ..   | 1.77 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.51 | ..                                                                           | ..                                 | ..                                           | ..                                                   | ..                                              | 1.58                                         | ..                                                  |
| 1897.....         | ..                                            | ..                                              | ..                                              | 2.29                                           | 1.69                                               | 1.61                                           | 1.70                                            | 1.45                     | 1.79 | 1.23 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.76 | ..                                                                           | 2.58                               | ..                                           | ..                                                   | ..                                              | 1.78                                         | ..                                                  |
| 1898.....         | ..                                            | ..                                              | ..                                              | 2.07                                           | 1.75                                               | 2.04                                           | 1.70                                            | 1.94                     | 2.15 | 1.55 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.68 | ..                                                                           | 2.36                               | ..                                           | ..                                                   | ..                                              | 2.09                                         | ..                                                  |
| 1899.....         | ..                                            | ..                                              | ..                                              | 1.66                                           | 1.61                                               | 1.49                                           | 1.71                                            | 2.06                     | 2.24 | 1.70 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.50 | ..                                                                           | 1.50                               | ..                                           | ..                                                   | ..                                              | 1.61                                         | ..                                                  |
| 1900.....         | ..                                            | ..                                              | ..                                              | 2.04                                           | 1.71                                               | 1.58                                           | 1.47                                            | 1.50                     | 1.73 | 1.28 | ..                                             | ..                                        | ..                                             | ..                   | ..   | ..   | ..                                                                           | 1.75                               | ..                                           | ..                                                   | ..                                              | 1.63                                         | ..                                                  |
| Ten year average  | ..                                            | ..                                              | ..                                              | 1.73                                           | 1.69                                               | 1.59                                           | 1.52                                            | 1.66                     | 1.98 | 1.46 | ..                                             | ..                                        | ..                                             | ..                   | ..   | 1.45 | ..                                                                           | 2.05                               | ..                                           | ..                                                   | ..                                              | 1.61                                         | ..                                                  |
| 1901.....         | ..                                            | ..                                              | ..                                              | 1.96                                           | 2.06                                               | 1.40                                           | 1.62                                            | 1.86                     | 2.11 | 1.75 | ..                                             | ..                                        | ..                                             | 1.98                 | ..   | ..   | ..                                                                           | 2.58                               | ..                                           | ..                                                   | ..                                              | 2.52                                         | ..                                                  |
| 1902.....         | ..                                            | ..                                              | ..                                              | 2.30                                           | 2.08                                               | 2.22                                           | 1.91                                            | 1.88                     | 2.06 | 1.71 | ..                                             | ..                                        | ..                                             | 2.24                 | ..   | ..   | ..                                                                           | 2.31                               | ..                                           | ..                                                   | ..                                              | 2.31                                         | ..                                                  |
| 1903.....         | ..                                            | ..                                              | ..                                              | 1.63                                           | 1.72                                               | 1.46                                           | 1.93                                            | 2.01                     | 2.14 | 1.64 | ..                                             | ..                                        | ..                                             | 1.78                 | ..   | ..   | ..                                                                           | 2.68                               | ..                                           | ..                                                   | ..                                              | 2.42                                         | ..                                                  |
| 1904.....         | ..                                            | ..                                              | ..                                              | 1.34                                           | 1.31                                               | 1.35                                           | 1.46                                            | 1.53                     | 1.73 | 1.42 | ..                                             | ..                                        | ..                                             | 1.31                 | ..   | ..   | ..                                                                           | 2.17                               | ..                                           | ..                                                   | ..                                              | 1.74                                         | ..                                                  |
| 1905.....         | ..                                            | ..                                              | ..                                              | 1.23                                           | 1.40                                               | 1.12                                           | 1.18                                            | 1.15                     | 1.34 | 1.07 | ..                                             | ..                                        | ..                                             | 1.54                 | ..   | ..   | ..                                                                           | 1.83                               | ..                                           | ..                                                   | ..                                              | 1.46                                         | ..                                                  |
| 1906.....         | ..                                            | ..                                              | ..                                              | 1.54                                           | 1.50                                               | 1.24                                           | 1.47                                            | 1.32                     | 1.58 | 1.22 | ..                                             | ..                                        | ..                                             | 1.68                 | 1.78 | ..   | ..                                                                           | 1.51                               | ..                                           | ..                                                   | ..                                              | 1.45                                         | ..                                                  |
| 1907.....         | ..                                            | ..                                              | ..                                              | 1.70                                           | 1.45                                               | 1.09                                           | 1.13                                            | 1.13                     | 1.33 | 1.02 | ..                                             | ..                                        | ..                                             | 1.61                 | 1.49 | ..   | ..                                                                           | 2.17                               | ..                                           | ..                                                   | ..                                              | 2.08                                         | 2.47                                                |
| 1908.....         | ..                                            | 2.28                                            | 2.17                                            | 1.74                                           | 1.98                                               | 1.41                                           | 1.69                                            | 1.66                     | 1.99 | 1.40 | ..                                             | 1.49                                      | ..                                             | 2.06                 | 2.15 | ..   | 1.83                                                                         | 2.17                               | ..                                           | ..                                                   | ..                                              | 1.40                                         | 2.15                                                |
| 1909.....         | ..                                            | 1.77                                            | 1.85                                            | 1.40                                           | 1.54                                               | 1.39                                           | 1.04                                            | 0.96                     | 1.38 | 0.97 | ..                                             | 1.26                                      | ..                                             | 1.63                 | 1.46 | ..   | 3.16                                                                         | 1.68                               | ..                                           | ..                                                   | ..                                              | 1.41                                         | 2.15                                                |
| 1910.....         | ..                                            | 1.86                                            | 1.92                                            | 1.78                                           | 1.40                                               | 1.30                                           | 1.10                                            | 0.87                     | 1.30 | 0.98 | ..                                             | 0.99                                      | ..                                             | 1.62                 | 1.54 | ..   | 1.86                                                                         | 1.80                               | ..                                           | ..                                                   | ..                                              | 1.37                                         | 2.35                                                |
| Ten year average  | ..                                            | 1.97                                            | 1.98                                            | 1.66                                           | 1.64                                               | 1.40                                           | 1.45                                            | 1.44                     | 1.70 | 1.32 | ..                                             | 1.25                                      | ..                                             | 1.74                 | 1.68 | ..   | 1.86                                                                         | 2.28                               | 2.04                                         | ..                                                   | ..                                              | 1.82                                         | 2.28                                                |
| 1911.....         | 1.12                                          | 1.07                                            | 1.06                                            | 0.87                                           | 0.96                                               | 0.74                                           | 0.79                                            | 0.61                     | 0.79 | 0.66 | ..                                             | 1.839                                     | 1.13                                           | 1.29                 | 1.11 | ..   | 1.48                                                                         | 1.12                               | 1.42                                         | ..                                                   | ..                                              | 1.41                                         | 1.99                                                |
| 1912.....         | ..                                            | 2.04                                            | 2.17                                            | 1.70                                           | 1.53                                               | 1.05                                           | 1.40                                            | 1.35                     | 1.56 | 1.39 | 1.80                                           | 1.44                                      | ..                                             | 2.02                 | 1.91 | ..   | 2.38                                                                         | 2.67                               | 1.65                                         | ..                                                   | ..                                              | 1.62                                         | 2.48                                                |
| 1913.....         | 1.93                                          | 2.17                                            | 2.85                                            | 1.78                                           | 1.80                                               | 1.42                                           | 1.26                                            | 1.00                     | 1.24 | 1.14 | 1.45                                           | 1.39                                      | ..                                             | 2.05                 | 1.91 | ..   | 2.42                                                                         | 1.62                               | 1.58                                         | 1.79                                                 | ..                                              | 1.97                                         | 2.49                                                |
| 1914.....         | 1.34                                          | 1.91                                            | 2.43                                            | 1.81                                           | 1.59                                               | 1.33                                           | 1.48                                            | 1.38                     | 1.65 | 1.43 | 1.89                                           | 1.32                                      | ..                                             | 1.48                 | 1.48 | ..   | 2.59                                                                         | 1.92                               | 1.41                                         | 1.69                                                 | 1.19                                            | 1.66                                         | 2.05                                                |
| 1915.....         | 1.56                                          | 1.37                                            | 1.55                                            | 1.60                                           | 1.18                                               | 1.05                                           | 1.10                                            | 0.97                     | 1.26 | 1.07 | 1.43                                           | 1.35                                      | ..                                             | 1.38                 | 1.30 | ..   | 2.09                                                                         | 1.79                               | 2.13                                         | 1.26                                                 | 1.02                                            | 1.84                                         | 2.62                                                |
| Five year average | 1.49                                          | 1.71                                            | 2.01                                            | 1.55                                           | 1.41                                               | 1.12                                           | 1.21                                            | 1.06                     | 1.30 | 1.14 | 1.48                                           | 1.33                                      | ..                                             | 1.64                 | 1.54 | ..   | 2.19                                                                         | 1.82                               | 1.64                                         | 1.58                                                 | 1.10                                            | 1.70                                         | 2.33                                                |
| 1916.....         | 1.52                                          | 1.48                                            | 1.50                                            | 1.86                                           | 1.80                                               | 1.58                                           | 1.77                                            | 1.53                     | 2.05 | 1.76 | 2.27                                           | 1.70                                      | 2.09                                           | 1.91                 | 1.99 | ..   | 2.79                                                                         | 2.15                               | 2.15                                         | 2.00                                                 | 1.44                                            | 2.03                                         | 2.59                                                |
| 1917.....         | 1.93                                          | 2.36                                            | 2.61                                            | 2.39                                           | 1.95                                               | 1.90                                           | 1.45                                            | 1.05                     | 1.25 | 1.04 | 1.55                                           | 1.50                                      | 1.58                                           | 1.99                 | 1.78 | ..   | 2.25                                                                         | 1.69                               | 1.62                                         | 1.41                                                 | 1.85                                            | 1.15                                         | 2.32                                                |
| 1918.....         | 1.79                                          | 1.74                                            | 1.72                                            | 1.56                                           | 1.53                                               | 1.38                                           | 1.07                                            | 1.09                     | 1.31 | 1.17 | 1.29                                           | 1.35                                      | 1.75                                           | 1.60                 | 1.55 | ..   | 2.07                                                                         | 1.42                               | 1.49                                         | 1.23                                                 | 1.72                                            | 1.31                                         | 1.97                                                |
| 1919.....         | 1.57                                          | 2.27                                            | 2.44                                            | 2.08                                           | 1.67                                               | 1.48                                           | 1.43                                            | 1.41                     | 1.73 | 1.47 | 1.56                                           | 1.94                                      | 2.41                                           | 1.99                 | 1.80 | ..   | 2.38                                                                         | 1.74                               | 1.72                                         | 1.56                                                 | 1.89                                            | 2.13                                         | 2.45                                                |
| 1920.....         | 1.66                                          | 2.02                                            | 2.31                                            | 1.79                                           | 1.69                                               | 1.88                                           | 1.89                                            | 2.02                     | 2.43 | 2.28 | 2.11                                           | 2.05                                      | 2.45                                           | 2.04                 | 2.04 | ..   | 2.82                                                                         | 2.41                               | 2.70                                         | 1.91                                                 | 1.84                                            | 2.44                                         | 2.98                                                |
| Five year average | 1.69                                          | 1.97                                            | 2.12                                            | 1.94                                           | 1.73                                               | 1.64                                           | 1.52                                            | 1.42                     | 1.75 | 1.54 | 1.76                                           | 1.71                                      | 2.06                                           | 1.92                 | 1.83 | ..   | 2.46                                                                         | 1.88                               | 1.94                                         | 1.62                                                 | 1.75                                            | 1.81                                         | 2.46                                                |

\* Figures based on climatic year from Oct. 1 to Sept. 30.  
† Figures based on calendar year from Jan. 1 to Dec. 31.  
‡ Average based on less than ten years.  
§ Average based on less than five years.





## APPENDIX B.

## GLOSSARY OF TERMS.

1. **Precipitation** is water that passes out of the atmosphere, in liquid or solid state, to the surface of the earth or bodies of surface water. It includes rain, snow, hail, sleet, dew and frost, mist and fog. It is the process by which atmospheric moisture becomes surface water. Rainfall and snowfall make up precipitation as ordinarily used.

(a) **Rainfall** is sometimes used in the sense of "precipitation," but it should become more general practice to limit its use to atmospheric moisture precipitated in the form of rain. Its common use in the broader sense undoubtedly is the result of the practice of measuring all forms of atmospheric precipitation in terms of "inches of rainfall."

(b) **Snowfall** is considered as snow, hail, sleet and other forms of precipitation, except rain, measured in depth in inches as it falls, but usually appears in records as its water equivalent.

(c) **Snow residuum** is the accumulated snow on the ground surface at the end of any period, or its water equivalent.

(d) **Water equivalent** is the depth of water in inches to which the snow on a given area would melt.

(e) **An isohyetal map** shows variation in amount of average precipitation over contiguous areas and isohyetal lines are used to connect contiguous points of equal precipitation, similar to contour lines.

2. **Evaporation** is the return of water from the earth or water surface to the atmosphere. It takes place in three or more ways, as from —

(a) Water, ice and snow surfaces; (b) land surfaces; and (c) vegetation, in the form of transpiration. Both evaporation and precipitation are the results of differences in temperature and atmospheric pressure.

3. **Seepage or percolation** of water is the movement of water underground, produced by hydrostatic pressure. Seepage waters reappear at the surface.

4. **Absorption** comprises all processes by which water is taken up by the earth's surface.

5. **Leakage** is the movement of water through artificial structures, and is produced by hydrostatic pressure.

6. **Discharge** is a general term for the rate of flow of water. In water-power practice, it is usually expressed in cubic feet per second (frequently abbreviated to second-feet); in water-works practice, it is customarily expressed in terms of million gallons per twenty-four hours.

7. The **drainage area** of a stream at a given point is the area of the surface of the earth which contributes its run-off to the stream above that point. Synonyms: Catchment area, watershed. (The latter is a misnomer as it is confused with the divide or boundary of the basin). The area used may be either gross, or the net exclusive of lake and pond areas, but it is assumed to be the former unless specified to the contrary.

8. The **run-off** of a given area of the surface of the earth is the quantity of water that is discharged from that area. Ordinary units of run-off are second-feet per square mile or run-off depth in inches.

(a) **Cubic foot per second** or **second-foot** is a unit of discharge of water flowing in a channel of one square foot in cross section at an average velocity of one foot per second.

(b) **Second-foot per square mile** is a unit of discharge indicating the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the run-off is distributed uniformly both as regards time and area.

(c) **Run-off depth in inches** is a unit of run-off indicating the depth to which the drainage area would be covered if all of the water flowing from it in a given period of time were conserved and uniformly distributed on the surface. It is used for comparing run-off with precipitation, which is usually expressed in depth in inches.

9. The **yield** of a drainage basin above any definite point is the collectable portion of the surface and underground waters. Any retention or detention of these waters within the drainage area, either naturally or artificially, varies the relation of yield to run-off.

Units of yield are the same as for run-off. In water-works practice, the terms "million gallons per day" or equivalents are used.

10. **Storage.** The word usually means —

(a) **Artificial storage** which is that water capacity which may be available to increase the extremely low flows for several days, weeks, months or even years. It is the retention of the flood waters for use during times of scarcity, and is usually located near the headwaters of a stream. Units for storage are million cubic feet, million gallons and acre-feet.

(b) There is usually some **natural storage** in the form of swamps, lakes and ponds, but its effect on stream flow cannot easily be separated from that of the rest of the drainage area. The same applies to ground water storage and stream channel storage.

11. **Pondage** is that water capacity created by any dam which tends to take care of the variations in draft at a water-power development. It is the retention for one or more days of the flow of a stream during hours of light load, for use during hours of heavy load.

## 12. Factors:

(a) **Load factor** is the ratio of the average to the maximum power load on a water-power plant during a given period of time, as a day, month or year. To be specific, this period should always be stated, as "daily load factor," etc. Frequently when plants operate for a period less than twenty-four hours, the load factor is expressed in terms of "load factor for hours when running;" but for purposes of stream-flow analysis all such factors should be reduced to the twenty-four hour basis.

In determining load factor, the "maximum load" should be the heaviest observed during the period. Usually, daily log records are kept, and switch-board instruments, when available, are read every half hour, or hour, and the highest of these observations is taken as the maximum.

The "average load" is the total energy output divided by the proper time unit.

(b) **Capacity factor** is the ratio of the average load in a given time period, as a day, to the total installed rated capacity of the equipment.

(c) **Utilization factor** is that coefficient by which the approximate theoretical energy-output must be multiplied to correspond to the actual delivered energy. It accounts for losses of all kinds, and for variations in operating conditions other than those included in the theoretical average plant efficiency.

The approximate **energy available** in a stream can be estimated by the following formulas:

$$\text{I. Net horse-power at the water-wheel realizing 80 per cent. of the theoretical power} = \frac{\text{cubic feet per second} \times \text{head}}{11}$$

If other than 80 per cent. is used as the efficiency of the equipment, then the formula should be —

$$\text{Net horse-power} = \frac{\text{cubic feet per second} \times \text{head} \times \text{efficiency}}{8.8}$$

$$\text{II. Electrical horse-power (73.3 over-all efficiency)} =$$

$$\frac{\text{cubic feet per second} \times \text{head}}{12}$$

or,

$$\text{III. Kilowatts} = \frac{\text{cubic feet per second} \times \text{head}}{16}$$

Losses allowed for in the utilization factor are leakage and waste in operation, etc.

Changes in efficiencies may be due to variations in load or variations in head from the average assumed for use in the formulas.

(d) **Concentration factor** is the ratio of the average flow during that part of the day pondage is being drawn upon to the 24 hour flow. The term is used as a measure of the increased flow made available at a given power development during part of the day as a result of the use of pondage.

(e) **Diversity factor** is the ratio of the sum of the maximum power demands of the subdivisions of any system or part of a system to the maximum demand of a whole system or part of a system under consideration, measured at the point of supply. The more noncoincident these peak surfaces are, the greater will be the diversity factor.

**Apparent Diversity factor** is the quotient obtained by dividing the total connected load by the station peak load. **True Diversity Factor** takes account of transmission losses.

(f) **Demand factor** is the maximum connected kilowatts of capacity divided into the actual kilowatts of demand, expressed in terms of per cent.

(g) **Peak** is the highest average load carried during one minute of any specified period. **Peak load** is the highest average load during one hour of any specified period.

### 13. River gaging stations.

(a) **Control** is the natural or artificial barrier, reef of ledges or other channel conditions below a gaging station which primarily affects and controls the relation between gage height and discharge at the station. It should be noted that the control may not be the same section for all stages.

(b) **Rating table** for a gaging station is a table showing the discharge corresponding to various gage heights at the station.

(c) **Rating curve** for a gaging station is a curve of relations between gage height and discharge.

(d) **Stage-discharge relation** is the relation between gage height and discharge as shown by the rating curve, q.v.

(e) **Water-stage recorder** is an instrument for automatically recording the elevation of the water surface, and the corresponding time.

14. **Regulation** is the artificial manipulation of the run-off of a stream.

15. **Fall** is the vertical distance between water surface levels at two points on a stream.

(a) **Gross head** is that portion of the fall which is available for producing power.

(b) **Net or effective head** is the residue left to produce energy after deducting all losses of head. These losses may be due to friction, irregularities of section and other causes.

(c) **Slope** is the total fall between two points divided by their distance apart, expressed in the same units.

### 16. Dams:

(a) **Crest of a dam** is, in general, the elevation at which overflow begins.

(b) **Height of a dam** should be specifically defined as either: (1) from the bottom of foundations, or (2) from the original bed of the river, to the crest or top of the dam. Top of the dam is used when there is no overflow.

17. **Backwater.** — This is the general term applied to the raising of water upstream from an obstruction to higher elevations than it would stand under similar conditions of flow with no obstruction. Such an obstruction may be a permanent structure like a dam or bridge pier, or may be a temporary obstruction like ice or logs. An unusually heavy discharge from a tributary may cause backwater in the main stream or vice versa.

(a) **Backwater curve** is a profile of the water surface upstream from an obstruction between such obstruction and the point where the backwater ceases. Such a curve or profile is used in determining the elevation of the water at any point under known or assumed conditions of flow. Each different set of conditions produces a different backwater curve.

(b) **Backwater effect** is the increase in water-surface elevation caused by an obstruction, and varies with the discharge. It may be obtained at any point by a comparison of the backwater curve and the natural profile of the stream with no obstruction, each referred to the same discharge. In discussions on this subject the term backwater effect is sometimes shortened to backwater.

18. An **average year** is frequently assumed to be that year obtained by averaging the duration curves for all the years. Otherwise, it is assumed to be that actual year in which the average natural run-off is the nearest to the arithmetical average for the entire period of record.



## APPENDIX C.

## GRADING OF NEW ENGLAND RUN-OFF RECORDS.

The grading or rating of run-off records in accordance with their relative accuracy has been found to be a difficult task. To recognize the fact that some run-off records have been more carefully and accurately kept than others, and that such records are more reliable and more useful was a simple matter for the Committee, but to devise a system by which records could be more or less automatically graded according to their reliability was much more difficult.

The chief difficulties in the way of grading records may be stated as:

1. Lack of intimate knowledge of all the stations. Factors or conditions having a marked effect on the accuracy of records may be unknown. New information bearing on the accuracy of past records has frequently come up, and presumably will continue to do so.

2. The difficulty of accurately balancing the importance of various items, as for example the relative weights of (1) a shifting control, (2) winter records based on estimates, and (3) the effect of say two readings a day with a fluctuating stage.

3. Difficulties of intercomparing records at different stations in view of the different conditions and circumstances under which records are obtained.

As a result of these difficulties the Committee came to the following conclusions:

1. That any rating giving the **percentage accuracy** of the records was manifestly impossible and that the grading must be according to **relative accuracy**.

2. That the relative grading as thus obtained in nowise constitutes the last word upon the records considered, but rather represents the best judgment of the Committee based upon the information available.

3. That there is no reason why accurate records should not be obtained at both open channel stations and stations at dams and power sites, and it has been arbitrarily assumed that the best records at the two kinds of stations are about on a par.

The system of grading finally adopted was based upon the principle of penalizing records a certain amount for each defect by which they fail to measure up to a perfect standard. The requirements necessary for accurate records were first classified with great detail and opposite each item was set an estimate of limiting penalties, the idea being that the worst case to be considered might be penalized an amount indicated by the upper limit.

Upon attempting to apply the system as thus worked out, it was frequently found difficult to decide under just what item a deduction for a given defect should be made. Hence, as a working proposition, it developed that all the deductions could best be made under the following general headings:

A. Open channel gaging stations.

1. Rating curve, how well defined.
2. Limits defined by discharge measurements.
3. Effect of ice, weeds or logs.
4. Records of stage, accuracy and frequency of readings.

B. Stations at dams and power plants.

1. Discharge measured by water wheels.
2. Normal discharge over dam or through waste gates or waste weirs.
3. Flood flows.
4. Records of stage and gate openings.

As the grading was further considered it became evident that many of the records were not of the same quality or degree of accuracy for their entire length. This is particularly true of open channel gaging stations on account of the marked development in the science of stream gaging during the last twenty years. The work of the U. S. Geological Survey in New England began about 1900 and much of the stream gaging work prior to 1911 or 1912 was of a reconnaissance nature. During this early period many difficulties in the way of good records were encountered and largely overcome by the use of the automatic gage, better methods of handling winter records as outlined in the monograph on that subject in the preliminary report of this Committee, and generally improved methods of stream gaging

work. Where proper, the grading has been divided into periods to correspond to these improvements.

The actual method of grading was as follows: For each open channel gaging station, a station description, list of discharge measurements up to 1920, and footnotes to daily and monthly discharge tables were assembled. Additional information was obtained from the station diaries kept at the U.S. Geological Survey office. The discharge measurements for the entire period were plotted both for the curve as a whole and also the lower section on a greatly enlarged scale, using different colors and symbols to designate the measurements of each year. For stations at dams and power sites, all published information was gathered together and additional information sought from the men most closely connected with the records. Each station was then considered in turn and deductions made under the four general headings.

The final rating of a record was obtained by adding together all the penalties and deducting from 100. The numerical result thus obtained was changed to a letter basis in order to avoid possible confusion in the meaning of the grading, and to prevent attempts to use the numerical rating as designating the limits of accuracy. The results of the grading have been stated as varying from A to D, A representing the best records and D the poorest. In addition a brief comment has been added in an attempt to characterize each record.

The Committee desires to make acknowledgement to Mr. P. L. Bean, former Chief Engineer of the Maine Public Utilities Commission and to Mr. G. C. Danforth, Chief Engineer of the Maine Water Power Commission for valuable information and assistance given by them covering the records in the State of Maine.

It should be stated that no reflection is intended or is attached to a low rating. In all cases of records furnished by private individuals or companies these have been given out freely for the benefit of the general public. These records have usually been obtained for specific purposes in connection with the operation of power plants. They are usually simply a side issue in the conduct of a power business and the accuracy of such records largely depends upon the local conditions.

Any consideration of the accuracy of run-off records naturally brings up the question of the uses of such records. These may be stated as follows:

(1) for estimating the power output obtainable from undeveloped water power sites and deciding upon the size of installation and cost of construction warranted.

(2) for estimating the maximum floods for which provision must be made.

(3) for determining the size and benefit derivable from a proposed storage reservoir for power, water supply or flood control purposes.

(4) for determining the best method of operating reservoirs and power plants already constructed and estimating future results.

(5) for estimating the value of diversions.

(6) for studying the science of hydrology.

In some cases the minimum flow may be required, in many instances the intermediate part of the duration curve for the purpose of estimating secondary power is of chief interest, while in other cases the total run-off, the distribution, the length and amount of the flood flows involving backwater, or some other special knowledge of run-off conditions may be desired.

A record which is given a low rating may nevertheless be of much value for some and possibly all of the uses listed above. In general, however, it is intended that the higher the rating of a record, the greater the confidence which may be placed in it.

# RESULTS OF GRADING.

| Station.                                               | Period. | Grade. | Remarks.                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------|---------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ST. JOHN RIVER BASIN.</b>                           |         |        |                                                                                                                                                                                                                                                                                                                                                                           |
| 1. St. John R. at Fort Kent, Me.....                   | 1905-15 | D      | Rating curve well defined below 15,000 sec. ft. Records missing, or affected by log jams or ice an average of 5 months per year.                                                                                                                                                                                                                                          |
| 2. St. John R. at Van Buren, Me. ....                  | 1908-20 | A -    | Open water rating curve extremely well defined, though no check measurements since 1915. Discharge during winter based on gage heights at Grand Falls and rating curve derived from measurements at Van Buren. Comparison of Van Buren and Grand Falls gage heights during open water period of 1916 showed Grand Falls record 11.9 per cent lower than Van Buren record. |
| 3. Aroostook R. at Fort Fairfield, Me.....             | 1903-10 | C      | Open water rating curve well defined and open water records good. Stage affected by ice, or gage heights missing from 4 to 6 months each year during which records missing or based on rough estimates.                                                                                                                                                                   |
| 4. St. Croix R. near Woodland, Me.....                 | 1902-11 | D -    | Rating curve defined by few measurements. Discharge relation affected by ice or log jams during much of year. Fluctuations in stage caused by mill after 1906. Gage read twice a day.                                                                                                                                                                                     |
| 5. Machias R. at Whitneyville, Me.....                 | 1903-15 | C      | No effect from ice usually assumed, though records since 1916 show ice effect from two to four months each winter. Operation of storage dam 200 ft. above gage causes considerable daily fluctuation during low stages. Some log driving and jams of short duration. Gage read once a day.                                                                                |
| <b>UNION RIVER BASIN.</b>                              |         |        |                                                                                                                                                                                                                                                                                                                                                                           |
| 6. W. Branch of Union R. at Amherst, Me.               | 1916-20 | B -    | Winter estimates based on backwater effect of ice. One to three discharge measurements each winter.                                                                                                                                                                                                                                                                       |
|                                                        | 1909-13 | B -    | Open water records fairly good, though occasional log jams occur, and lower part of rating curve is only fairly well defined. Discharge relation affected by ice 2 to 4 months each year, when records based on rough estimates.                                                                                                                                          |
| <b>PENOBSCOT RIVER BASIN.</b>                          |         |        |                                                                                                                                                                                                                                                                                                                                                                           |
| 7. West Branch of Penobscot R. at Millinocket, Me..... | 1914-19 | B      | One to three discharge measurements each winter and estimates during ice conditions based on gage heights corrected for backwater.                                                                                                                                                                                                                                        |
|                                                        | 1901-20 | B      | Only monthly figures available. When flow is below 2 500 sec. ft., all the water generally flows through the wheels of the mill which have been care-                                                                                                                                                                                                                     |



|                                                     |         |     |                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------------------------|---------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8. West Branch of Penobscot R. near Medway, Me..... | 1916-20 | A - | Rating curve well defined although the control shifted in 1917 and again in 1920. Effect of ice not great. Some trouble with gage heights previous to 1919.                                                                                                                                                                                                                      |
| 9. Penobscot R. at West Enfield, Me.....            | 1902-13 | B - | Rating curve well defined and open water records fairly good. Discharge relation affected by ice 3 to 4 months each year, during which records are missing or are based on rough estimates. Two gage readings a day previous to 1912. Some daily fluctuation. Passadumkeag R. enters below the station, but above the control. (Passadumkeag Rips.)                              |
| 10. E. Branch Penobscot R. at Grindstone, Me.....   | 1914-20 | A   | Rating curve well defined. Automatic gage. Winter estimates ascertained by comparison with records at Sunk Haze Rips, where frequent winter measurements are made in connection with distribution of water at Old Town, deducting for Passadumkeag R. and intervening area.                                                                                                      |
| 11. Mattawamkeag R. at Mattawamkeag, Me.....        | 1902-13 | B - | Rating curve well defined though velocities sluggish at low stages, and occasional log jams affect stage discharge relation. Discharge relation affected by ice 3 to 4 months each year, during which records are missing or are based on rough estimates. Gage usually read once daily (except Sunday) and three times a week in winter. Little effect from storage regulation. |
|                                                     | 1914-20 | A - | Two to four discharge measurements each winter and estimates during ice conditions based on gage heights corrected for backwater.                                                                                                                                                                                                                                                |
|                                                     | 1902-13 | B - | Rating curve well defined, though there is an occasional effect from log jams and possibly an occasional backwater effect from the Penobscot River. Discharge relation affected by ice 3 to 4 months each year, during which records are missing or are based on rough estimates. Gage read twice daily except in winter when it is read twice a week.                           |
| 12. Piscataquis R. near Foxcroft, Me.....           | 1914-20 | A - | Two to five discharge measurements each winter and estimates during ice conditions based on gage heights corrected for backwater.                                                                                                                                                                                                                                                |
|                                                     | 1902-15 | D   | Low water rating curve only fairly well defined. Occasional log jams. Winter records either missing, rough estimates, or open water rating curve applied. Gage read twice a day. Several mills above that cause fluctuation in low water flow.                                                                                                                                   |
|                                                     | 1916-20 | C + | Two or three discharge measurements each winter and estimates based on backwater effect.                                                                                                                                                                                                                                                                                         |

# RESULTS OF GRADING.

| Station.                                    | Period.            | Grade. | Remarks.                                                                                                                                                                                                                                                                          |
|---------------------------------------------|--------------------|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PENOBSCOT RIVER BASIN — (Cont.).            |                    |        |                                                                                                                                                                                                                                                                                   |
| 13. Passadumkeag R. at Lowell, Me. ....     | 1915-20            | B -    | Location of gage changed Oct. 1, 1917. Rating curves fairly well defined though discharge measurements not very numerous. Ice three to four months each year during which estimates based on backwater effect determined by three to eight discharge measurements each winter.    |
| 14. Kenduskeag Stream near Bangor, Me. .... | 1908-13            | C +    | Rating curve well defined, though control may shift slightly. Ice two to four months each year. Winter records either rough estimates or open water rating curve used. Two readings a day, three times a week in winter.                                                          |
|                                             | 1914-20            | B +    | One to four discharge measurements each winter and estimates based on backwater effect.                                                                                                                                                                                           |
| ST. GEORGE RIVER BASIN.                     |                    |        |                                                                                                                                                                                                                                                                                   |
| 15. St. George R. at Union, Me. ....        | 1913-14            | B      | Rating curve fairly well defined, although a big shift in the control was indicated by discharge measurements in 1915. Records missing from Jan. 14 to March 2, 1914. Possibly some ice effect in December, 1914, but none assumed. Gage read once a day.                         |
| KENNEBEC RIVER BASIN.                       |                    |        |                                                                                                                                                                                                                                                                                   |
| 16. Moose R. near Rockwood, Me. ....        | 1902-08<br>1910-12 | C -    | Lower part of rating curve fairly well defined. Possibly backwater effect from Moosehead Lake. Winter records either missing or rough estimates. Gage read twice a day. During log driving season (say two months) a fluctuation of a foot or more likely each day.               |
| 17. Kennebec R. at The Forks, Me. ....      | 1902-12            | D +    | Rating curve fairly well defined. Stage discharge relation affected by log jams and by backwater from Dead River. Records doubtful during log driving season (up to three months) on account of daily fluctuation and log jams. Winter records either missing or rough estimates. |
|                                             | 1913-20            | B +    | Automatic gage installed in 1912. Winter estimates based on gage heights corrected for backwater effect determined by one to three discharge measurements each winter. Gage relocated in 1919.                                                                                    |
| 18. Kennebec R. at Bingham, Me. ....        | 1907-10            | C -    | Rating curve well defined, though only nine discharge measurements. Ice four to five months during which period records based entirely on estimates from other stations. For two months considerable daily fluctuation in                                                         |

|                                           |                    |          |                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------|--------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 19. Kennebec R. at North Abson, Me.       | 1891-97            | B -      | When flow is below 3 800 sec. ft., generally all measured by waterwheels rated at Holyoke under approximately same head. Some uncertainty regarding condition of flashboards.                                                                                                                       |
| 20. Kennebec R. at Waterville, Me.        | 1892-1920          | B -      | When flow is below 3 800 sec. ft., generally all measured by waterwheels rated at Holyoke under approximately same head. Some uncertainty regarding condition of flashboards.                                                                                                                       |
| 21. Dead River at The Forks, Me.          | 1901 07<br>1910 14 | B -      | Rating curve well defined except below 400 sec. ft. Winter records missing or based on rough estimates. Log driving may have caused daily fluctuation during part of year. Gage read twice a day ordinarily; three times a week in winter.                                                          |
| 22. Sandy R. at Farmington, Me.           | 1915-20            | B +      | Winter estimates based on gage heights corrected for backwater determined by one to three discharge measurements each winter.                                                                                                                                                                       |
| 23. Androscoggin R. at Errol Dam, N. H.   | 1910-15            | C +      | Rating curve fairly well defined except no discharge measurements above 1520 sec. ft. Discharge relation seriously affected by ice for three to four months each winter and records based on estimates. Gage read once a day. Water power plant at Phillips may have caused some daily fluctuation. |
| 24. Androscoggin R. at Berlin, N. H.      | 1905 20<br>1913 20 | B -<br>B | Flow measured by opening of sluice gates which have been rated approximately by current meter measurements. Low water flows check up fairly well with records at Berlin.                                                                                                                            |
| 25. Androscoggin R. at Rumford Falls, Me. | 1892-20            | A        | Flow up to 2200 sec. ft. measured by wheels rated from Holyoke tests. 24-hour power. Dam irregular in shape and not in good condition for weir measurements, but due to storage control flow does not usually exceed 2200 sec. ft. more than two to three months a year.                            |
| 26. Magalloway R. at Aziscohos Dam, Me.   | 1912-20            | B -      | Flow computed from discharge over the dam by use of the Francis weir formula with modified coefficient, and the quantities passing through the various wheels of the power station and mills, which have been carefully rated.                                                                      |
|                                           |                    |          | Flow measured by the openings of two gates shaped very much like cylinder gates of water wheels. Approximately rated by means of current meter measurements.                                                                                                                                        |

# RESULTS OF GRADING.

| Station.                                             | Period.   | Grade. |                                                                                                                                                                                                                                                                                                                           |
|------------------------------------------------------|-----------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ANDROSCOGGIN RIVER BASIN — (Cont.).                  |           |        |                                                                                                                                                                                                                                                                                                                           |
| 27. Little Androscoggin R. near S. Paris, Me.        | 1913-20   | A -    | Rating curve well defined below 700 sec. ft. Gage read to tenths once daily. Stage discharge relation not affected by ice.                                                                                                                                                                                                |
| PRESUMPSCOT RIVER BASIN.                             |           |        |                                                                                                                                                                                                                                                                                                                           |
| 28. Presumpscot R. at outlet of Sebago Lake, Me..... | 1887-1903 | B -    | Flow determined from discharge of sluice gates and waste over dam.                                                                                                                                                                                                                                                        |
|                                                      | 1904-1920 | A      | Discharge measured by water wheels with use of Allen turbine meter. Amount of flow over dam and through waste gates small. About 13 sec. ft. diverted for Portland Water Supply which is not included in published records.                                                                                               |
| SACO RIVER BASIN.                                    |           |        |                                                                                                                                                                                                                                                                                                                           |
| 29. Saco R. near Center Conway, N. H.....            | 1903-12   | D +    | Rating curve only fairly well defined. Winter records missing.                                                                                                                                                                                                                                                            |
| 30. Saco R. at Cornish, Me.....                      | 1916-18   | B      | Rating curve fairly well defined between 1,000 and 7,000 sec. ft. Winter records determined by correction of gage heights for backwater as determined by one to three discharge measurements each winter. Gage read twice a day. Fluctuation caused by power plant at Hiram.                                              |
|                                                      | 1919-20   | A      | Rating curve well defined. Automatic gage.                                                                                                                                                                                                                                                                                |
| 31. Saco R. at West Buxton, Me.....                  | .....     | ..     | Not rated.                                                                                                                                                                                                                                                                                                                |
| 32. Ossipee R. at Cornish, Me.....                   | 1916-20   | B +    | Rating curve well defined. Winter records affected by ice three to four months and estimates based on gage heights corrected for backwater as determined by one to three discharge measurements each winter. Gage read once a day. There may be some daily fluctuation due to operation of power station at Keisar Falls. |
| MERRIMACK RIVER BASIN.                               |           |        |                                                                                                                                                                                                                                                                                                                           |
| 33. Pemigewasset R. at Plymouth, N. H....            | 1903-18   | C      | Rating curve fairly well defined above 600 sec. ft, but has shifted widely below that point, and low water records much in doubt. Discharge relation affected by ice for two to three months and records based on rough estimates. Two readings a day except Sundays.                                                     |
|                                                      | 1919-20   | B +    | Sufficient discharge measurements to define lower part of rating curve fairly well. Winter records based on correction of gage heights for backwater as                                                                                                                                                                   |

affected by ice from one to three months each winter. Winter estimates based on records at other stations. Gage read twice daily except Sundays.

Rating curve fairly well defined. First winter discharge measurements in 1918. Reliability of gage readings questionable prior to 1918.

Flow through wheels up to 2 700 sec. ft. determined from kilowatt output based on current meter measurements in 1904-05. Flow over dam and waste-ways determined from Francis formula with modified coefficients. Mean daily flow taken as average of flow at 7.30 A.M., 12 M. and 5 P.M.

Flow up to 9 000 to 9 500 sec. ft. measured by water wheels tested at Holyoke and checked by measurements in place. Mostly 8 to 9 hour power. For 9 months or more flow over dam determined by depth over flashboards which are kept in excellent condition and their height determined by levels. When flashboards are off flow computed by Francis Lawrence dam formula. When condition of flashboards is unknown, flow determined from rating curve for height of river below dam.

Rating curve fairly well defined up to 600 sec. ft. Discharge relation affected by ice from two to four months. Estimates during ice conditions based on backwater effect determined by two discharge measurements each winter. Gage read twice daily. Very little fluctuation caused by operations of small mills above gaging station.

Rating curve only fairly well defined. Discharge relation seriously affected by ice from two to four months. Winter estimates based on backwater effect due to ice determined by two to three discharge measurements each winter. Gage read twice daily. Effect of pondage regulation uncertain.

Rating curve well defined. Discharge relation affected very little by ice. Gage read twice daily. No daily fluctuation due to pondage. Some doubt as to absolute reliability of gage readings.

Rating curve fairly well defined. Stage discharge relation affected by ice. Winter estimates based on corrections for backwater determined by one or two discharge measurements each winter. Large daily fluctuation. Operation of recording gage not very satisfactory.

|           |     |  |
|-----------|-----|--|
| 1916-20   | D + |  |
| 1904-16   | C   |  |
| 1880-1920 | A   |  |
| 1918-20   | B + |  |
| 1918-20   | B - |  |
| 1918-20   | A - |  |
| 1918-20   | B   |  |

35. Merrimack R. at Garvins Falls, N. H.

36. Merrimack R. at Lawrence, Mass. ....

37. Smith R. near Bristol, N. H. ....

38. Contoocook R. near Elmwood, N. H. ...

39. Blackwater R. near Contoocook, N. H.

40. Suncook R. at North Chichester, N. H.



# RESULTS OF GRADING.

| Station.                                                            | Period.   | Grade. | Remarks.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------|-----------|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MERRIMACK RIVER BASIN—(Cont.).                                      |           |        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 41. Souhegan R. at Merrimack, N. H. ....                            | 1909-14   | B      | Rating curve well defined. Gage read twice a day. Some fluctuation caused by operation of mills at Milford. Stage discharge relation not much affected by ice except in severe winters.                                                                                                                                                                                                                                                                                                                                                                    |
| 42. South Branch Nashua R., at Clinton, Mass. (Wachusett) . . . . . | 1915-20   | A      | Automatic gage since 1913.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                                                     | 1896-1920 | A      | 1896-98. Flow measured at an unused dam in Clinton. Automatic gage. Planked measuring flume for rating dam by current meter measurements. 1898-1911. Flow measured at a weir constructed in aqueduct. Automatic gage and special section prepared for rating weir by current meter measurements. 1911-20. Flow measured by Venturi meters rated by current meters. Water wasted over flashboards determined from Francis weir formula, over masonry crest of overflow by coefficients determined from experiments at Cornell. Monthly flows only computed. |
|                                                                     | 1901-20   | D      | Flow up to 350 sec. ft. determined by wheel ratings based on Holyoke tests checked by current meter measurements in place. Flow over dam on which 8 in. to 10 in. of flashboards are carried computed from Francis formula. Daily flow taken as mean of forenoon and afternoon readings, but low flows seriously affected by the operation of pondage.                                                                                                                                                                                                     |
| 44. Sudbury R. near Framingham, Mass. . . . .                       | 1875-97   | A      | Flow measured by weirs rated by current meter measurements.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                                                     | 1898-1920 | A—     | Since 1898 water from Wachusett Reservoir has been discharged into Sudbury system, and Sudbury yield determined by process of subtraction. Since 1912 water drawn from Sudbury system into Weston Aqueduct has been measured by Venturi meters.                                                                                                                                                                                                                                                                                                            |
| 45. Pawtuxet R. at Fiskeville, R. I. ....                           | 1916-20   | A      | Station at unused dam of B. B. Knight & Co. Rating curve determined by experiments on model and later checked by current meter measurements. Automatic gage.                                                                                                                                                                                                                                                                                                                                                                                               |
| 46. Quinebaug R. at Jewett City, Conn. . . . .                      | 1918-20   | A      | Rating curve well defined. Little if any effect from ice. Operation of auto-                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

|                                                                 |                                     |               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------------------------|-------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 47. Connecticut R. at First Lake near<br>Pittsburgh, N. H. .... | 1917-18                             | B +           | During 1917 and part of 1918 discharge determined by openings of sluice gate rated by current meter measurements. Rating fairly good. Sluice gate ratings affected by ice.                                                                                                                                                                                                                                                                                                                                                                                                          |
| 48. Connecticut R. at Orford, N. H. ....                        | 1919-1920<br>1900-1914              | A<br>B +      | Since July, 1918, records obtained at open channel gaging station. Rating curve well defined. Not affected by ice. Operation of automatic gage satisfactory.<br>Rating curve well defined, though small shifts in rating curve frequent. Stage discharge relation affected by ice about three months a year on an average. Winter discharge measurements each year since 1903 except in 1911, and winter estimates probably better than at most stations during this period.                                                                                                        |
| 49. Connecticut R. at Sunderland, Mass..                        | 1915-1920<br>1904-1906              | A -<br>B -    | Flashboards at Wilder dam raised in 1915, and different rating curves required for different heights of flashboards. These rating curves fairly well defined, and condition of flashboards fairly well known during greater part of the year. Winter flows determined from gage heights corrected for backwater effect of ice determined by 3 to 6 discharge measurements each winter.<br>Rating curve well defined above 7 000 sec. ft., not very well defined below. Stage discharge relation affected by ice two to three months, during which period estimates are approximate. |
| 50. Connecticut R. at Holyoke, Mass.                            | 1907-1914<br>1915-1920<br>1880-1899 | B +<br>A<br>B | Rating curve well defined. One to three winter discharge measurements usually available for winter estimates.<br>Automatic gage since 1916. Several discharge measurements each winter and flows computed from gage heights corrected for backwater due to ice.<br>Flow up to about 8,000 sec. ft. determined by water wheel ratings based on Holyoke tests. Coefficients for computing waste over dam uncertain.                                                                                                                                                                   |
| 51. Passumpsic R. at Pierce's Mills, near<br>St. Johnsbury, Vt. | 1909-15<br>1916-20                  | B -<br>B      | Rating curve only fairly well defined. Stage discharge relation affected by ice two to four months. Winter records missing or based on rough estimates. Two gage readings a day. Some fluctuation in stage due to operation of mills.<br>Winter records based on gage heights corrected for backwater determined by discharge measurements.                                                                                                                                                                                                                                         |

# RESULTS OF GRADING.

| Station.                                     | Period.   | Grade. | Remarks.                                                                                                                                                                                                                                                                                                                 |
|----------------------------------------------|-----------|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CONNECTICUT RIVER BASIN — (Cont.).           |           |        |                                                                                                                                                                                                                                                                                                                          |
| 52. White R. at West Hartford, Vt.....       | 1915-20   | A —    | Rating curve well defined. Ice one to three months. Winter records based on gage heights corrected for backwater determined by discharge measurements. Gage read twice a day. Flow probably affected somewhat by operation of mills at Sharon.                                                                           |
| 53. Ashuelot R. at Hinsdale, N. H.....       | 1907-09   | B      | Rating curve well defined. Winter discharge based on climatological data and approximate rating curves. Two gage readings a day. Possibly some daily fluctuation.                                                                                                                                                        |
|                                              | 1914-20   | A —    | Winter records based on gage heights corrected for backwater determined by discharge measurements.                                                                                                                                                                                                                       |
| 54. Millers R. near Winchendon, Mass....     | 1916-20   | B —    | Control shifting and rating curves only fairly well defined. Two to four discharge measurements each winter, but on account of large daily fluctuation, water frequently overflows the ice, causing variable backwater effect.                                                                                           |
| 55. Millers R. at Erving, Mass.....          | 1914-1915 | B      | Rating curve well defined, though not many discharge measurements below 200 sec. ft. Ice one to three months. Variable backwater effect of ice caused by fluctuation in stage due to power plant operation. Gage read twice daily, and results corrected by coefficient determined after installation of automatic gage. |
|                                              | 1916-20   | A —    | Automatic gage.                                                                                                                                                                                                                                                                                                          |
| 56. Sip Pond Brook<br>near Winchendon, Mass. | 1916-17   | B      | Rating curve only fairly well defined. Automatic gage except for June, 1916 and Dec. 13, 1916 to June 26, 1917. Considerable daily fluctuation. Stage discharge relation affected by ice about two months, and estimates based on gage heights corrected for backwater effect determined by discharge measurements.      |
|                                              | 1918-20   | A —    | Rating curve well defined except below 20 sec. ft. when it is fairly well defined. Automatic gage.                                                                                                                                                                                                                       |
| 57. Priest Brook near Winchendon, Mass.      | 1916-20   | A —    | Rating curve well defined. Stage discharge relation not much affected by ice in open winters; affected two months or so in severe winters. Gage read                                                                                                                                                                     |

|                                                                                  |           |     |                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------------------|-----------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| affected by ice for short periods. Gage read twice a day. No pondage regulation. |           |     |                                                                                                                                                                                                                                                                                                              |
| 59. Moss Brook at Wendell Depot, Mass.                                           | 1916-20   | A   | Rating curve well defined. Stage discharge slightly affected by ice from one to three months. Gage read twice daily. No pondage regulation.                                                                                                                                                                  |
| 60. Deerfield R. at Charlemont, Mass.....                                        | 1913-1920 | A   | Rating curve extremely well defined. Automatic gage. Stage discharge relation affected by ice two to three months. Numerous winter discharge measurements and power station records at Shelburne Falls available for comparison.                                                                             |
| 61. Deerfield R. at Shelburne Falls, Mass.                                       | 1907-13   | A   | (At power station of Greenfield El. Lt. Co.) Discharge determined by water wheels rated in place with current meters. Gate openings and head read hourly. One foot of flashboards on dam. Boards were kept in good condition.                                                                                |
| 62. Ware R. at Gibbs Crossing, Mass.....                                         | 1914-15   | B + | (At No. 2 power station of New England Power Co.) Discharge determined from power output. Wheel ratings from Holyoke test. Flashboards kept in good condition except in times of high water.                                                                                                                 |
| 63. Swift R. at West Ware, Mass.....                                             | 1912-20   | A - | Rating curve well defined. Stage discharge relation seriously affected by ice from one to three months. Fluctuating stage causes variable back water effect under ice conditions.                                                                                                                            |
| 64. Quaboag R. at West Brimfield, Mass.                                          | 1912-20   | B + | Rating curve fairly well defined. Stage discharge relation affected by ice one to three months each winter. Flow computed from gage heights corrected for backwater effect determined by discharge measurements.                                                                                             |
| 65. Westfield R. at Knightville, Mass.....                                       | 1909-15   | A - | Rating curve well defined, although there has been a slight shift in control. Stage discharge relation affected by ice from one to three months. The diurnal fluctuation breaks up the ice and causes a variable backwater effect.                                                                           |
|                                                                                  |           | B - | Rating curve fairly well defined, although not many measurements between 60 and 240 sec. ft. Stage discharge relation affected by ice from one to three months. Winter records based almost entirely on climatological data and comparison with other streams. Gage read twice daily. No pondage regulation. |
|                                                                                  | 1916-20   | B   | Winter estimates based on gage heights corrected for backwater determined by two to four discharge measurements each winter.                                                                                                                                                                                 |

# RESULTS OF GRADING.

| Station.                                                                         | Period.            | Grade.   | Remarks.                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------|--------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CONNECTICUT RIVER BASIN — (Cont.).<br>66. Westfield. R near Westfield, Mass..... | 1914-20            | A        | Rating curve well defined except for lower part of curve used in 1914 and 1915. Stage discharge relation usually affected by ice for less than a month. Discharge measurements each winter. Automatic gage.                                                                                                                                                                                         |
| 67. Middle Branch of Westfield R. at Goss Heights, Mass.....                     | 1910-15            | B —      | Control shifting and rating curves only fairly well defined. Discharge relation affected by ice from one to four months. Discharge measurements each winter. Gage read twice daily prior to 1912. Automatic gage since 1912.                                                                                                                                                                        |
| 68. Westfield Little R. near Westfield, Mass.....                                | 1916-20<br>1905-09 | B<br>A — | Winter records based on gage heights corrected for backwater effect. Automatic gage not working properly at times and records based on comparison with Knightville.<br>Rating curve well defined. Stage discharge relation affected by ice one to two months. During 1906-07, winter flows determined from weir located a short distance downstream. Several winter discharge measurements in 1909. |
| 69. Farmington R. near New Boston, Mass.                                         | 1910-20            | A        | Flow diverted for Springfield water supply measured by Venturi meter. Low water flow not diverted (below 163 second feet) measured by sharp crested weir 12 ft. long. Flow above 163 sec. ft. determined by head on concrete dam 155.4 ft. long. Automatic gage.                                                                                                                                    |
| 70. Hockanum R. near East Hartford, Conn.                                        | 1913-20<br>1919-20 | A —<br>A | Rating curve well defined. Stage discharge relation seriously affected by ice, with ice jams occasionally forming. Winter discharge measurements each year except 1916. Automatic gage.<br>Rating curve rather well defined. Discharge relation not affected by ice. Operation of automatic gage satisfactory.                                                                                      |
| HOUSATONIC RIVER BASIN.<br>71. Housatonic R. at Great Barrington, Mass.          | 1913-20            | B        | Rating curve well defined. Stage discharge relation not much affected by ice. Gage read twice daily. Some daily fluctuation on account of operation of mill.                                                                                                                                                                                                                                        |



ords of power output at power station just above gaging station and height of water on dam available. Gage read twice daily before power plant was placed in operation.

# Automatic Gage.

Rating curve not very well defined. Discharge records affected by ice from two to three months each winter. Records missing or no estimates made during winter for 49 days in 1913-14 and 79 days in 1914-15. Gage read twice daily except in winter when once a day. Power plant above causes small daily fluctuation in low water.

Rating not very well defined. Winter records missing for three to four months. Gage read twice daily. Probable not much daily fluctuation from use of pondage.

Rating curve defined somewhat better than in previous period. Winter estimates based on gage heights, observers notes and weather records.

Rating curve fairly well defined. Winter records based on gage heights corrected for backwater determined by discharge measurements beginning in 1916-17.

Rating curve well defined. Winter records based on gage heights corrected for backwater determined by three to four discharge measurements each winter. Automatic gage.

Rating curve not very well defined. Winter records missing for about 3½ months each year. Gage read twice daily. Daily flow affected at low stages by operation of pondage.

Rating curve only fairly well defined. Winter records missing or based on climatological data. Gage read twice daily. Some fluctuation in stage on account of operation of pondage.

Automatic gage. Winter records missing in 1917 and 1918.

Rating curve extremely well defined. Winter records based on gage heights corrected for backwater determined by discharge measurements. Occasionally trouble with operation of automatic gage.

73. Pomperaug R. at Bennett's Bridge,  
Conn.....

74. St. Lawrence River BASIN.  
Otter Creek at Middlebury, Vt.....

75. Winooski R. at Montpelier, Vt.....

76. Winooski R. at Richmond, Vt.....

77. Dog. R. at Northfield, Vt.....

78. Lamoille R. at Cady Falls, Vt.....

1915-20

1913-16

1903-07

1910-15

1916-20

1914-20

1903-07  
& 1910

1909-14

1915-20

1913-20

A

C +

D +

C +

B

A

D

C

B -

A -

# RESULTS OF GRADING.

| Station.                                   | Period. | Grade. | Remarks.                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------|---------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ST. LAWRENCE RIVER BASIN — (Cont.).</b> |         |        |                                                                                                                                                                                                                                                                                                               |
| 79. Lamolite R. at Johnson, Vt.....        | 1910-13 | D      | Rating curve not very well defined. Winter records missing. Gage read twice daily.                                                                                                                                                                                                                            |
| 80. Green R. at Garfield, Vt.....          | 1915-20 | A      | Sharp crested weir with rating curve determined by Francis weir formula with correction determined by current meter measurements. Weir flooded out when flow exceeds 130 sec. ft. and results somewhat uncertain. Stage discharge relation not affected by ice. Gage read twice daily. No pondage regulation. |
| 81. Missiquoi R. near Richford, Vt.....    | 1909-15 | D —    | Rating curve fairly well defined. Winter records missing. Gage read twice daily. Considerable daily fluctuation on account of operation of pondage.                                                                                                                                                           |
|                                            | 1916-20 | B +    | Winter records based on gage heights corrected for backwater determined by several current meter measurements each winter.                                                                                                                                                                                    |
| 82. Clyde R. at West Derby, Vt.....        | 1909-15 | C —    | Rating curve not well defined. Winter records missing or based on climatological data. Gage read twice daily.                                                                                                                                                                                                 |
|                                            | 1916-20 | B —    | Winter records based on gage heights corrected for backwater determined by one to three current meter measurements each winter. Automatic gage.                                                                                                                                                               |

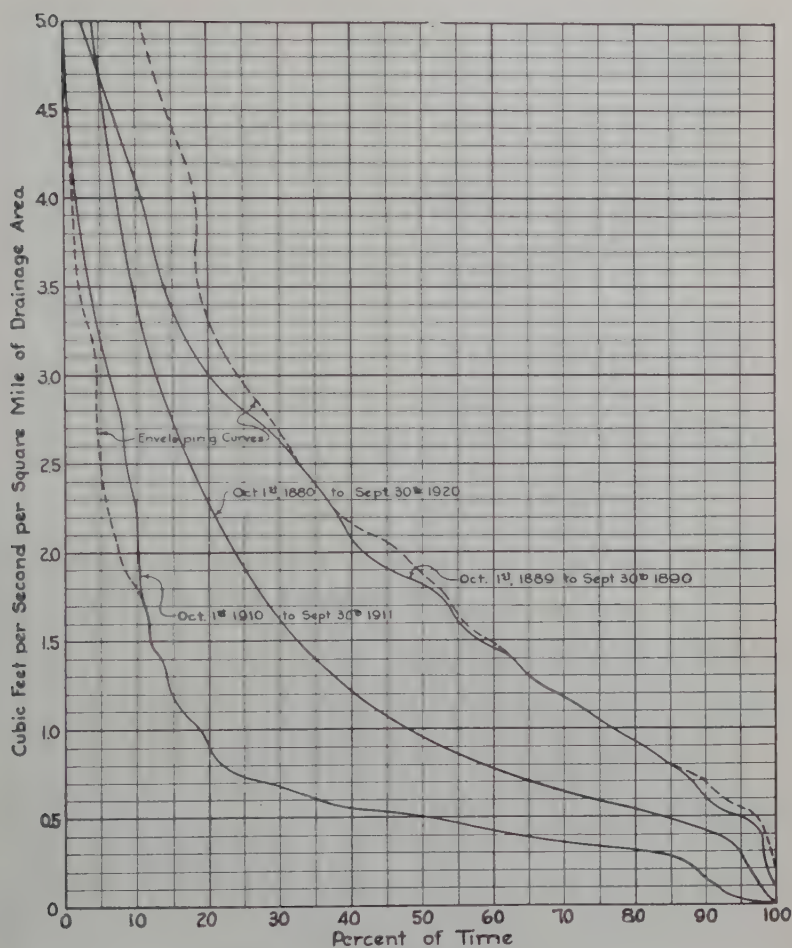


FIG. 7. — DURATION CURVES

Forty-Year Average, Enveloping Curves, and Maximum and Minimum years.

Merrimack River at Lawrence, Mass.

Net drainage area before March 6, 1898, 4 570 sq. mi.

Net drainage area since March 6, 1898, 4 452 sq. mi.

Based on climatic year, October 1, to September 30.

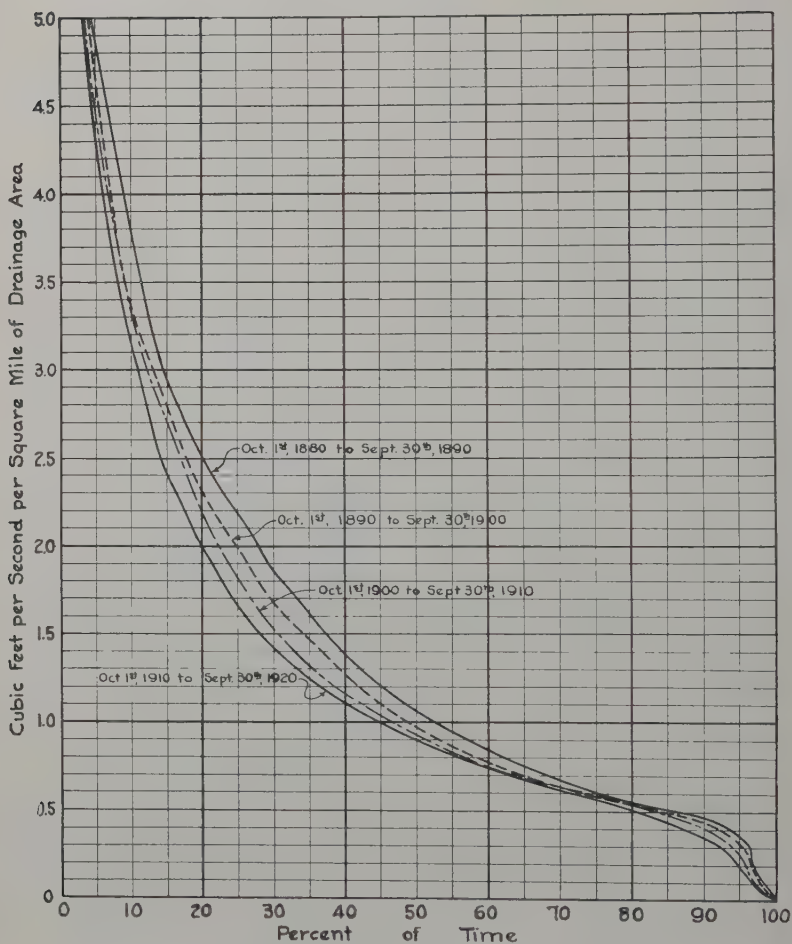


FIG. 8. — DURATION CURVES

Comparison of Ten-Year Periods Merrimack River at Lawrence, Mass.

Net drainage area before March 6, 1898, 4 570 sq. mi.

Net drainage area since March 6, 1898, 4 452 sq. mi.

Based on climatic year, October 1 to September 30.

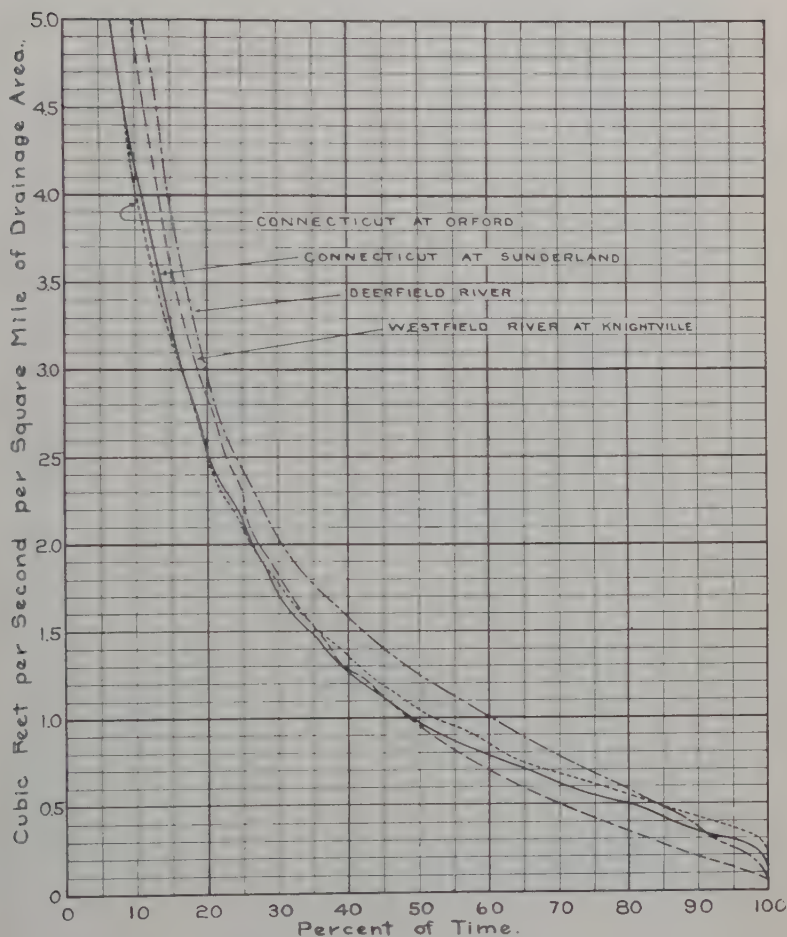


FIG. 9. — DURATION CURVES

Ten-Year Period 1911-1920

Connecticut River at Orford (3 100 sq. mi.)

Connecticut River at Sunderland (8 000 sq. mi.)

Deerfield River at Shelburne Falls (501 sq. mi.) and Charlemont (362 sq. mi.)

Westfield River at Knightville (162 sq. mi.)

Based on climatic year October 1 to September 30.



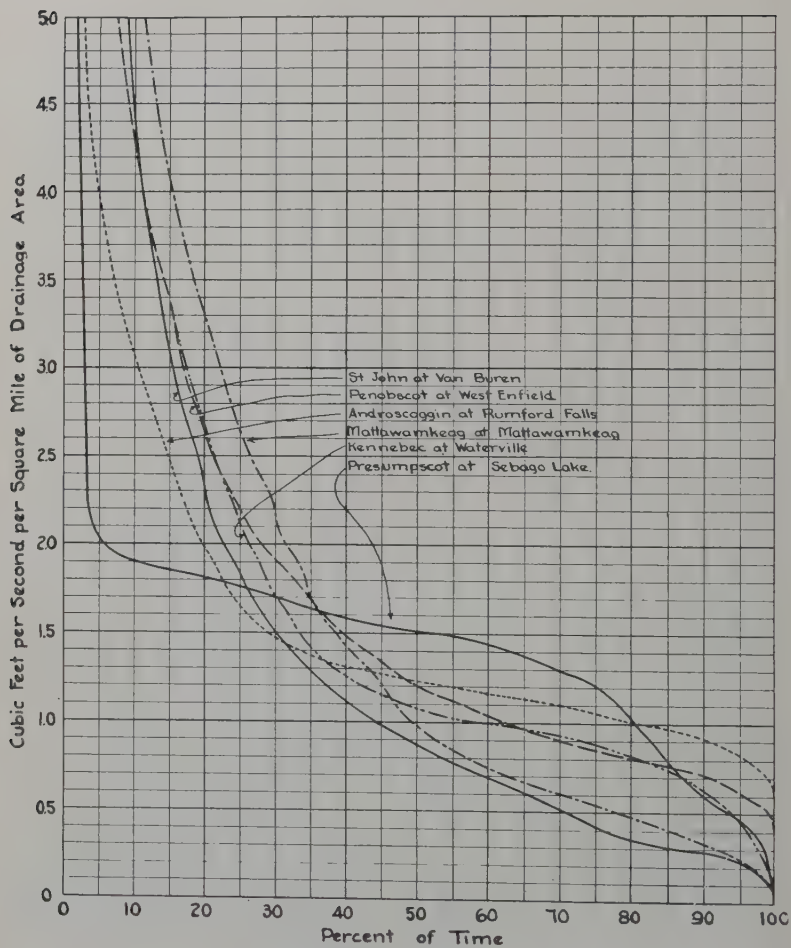


FIG. 10. — DURATION CURVES

Eight-Year Period, 1913-1920

St. John River at Van Buren (8 270 sq. mi.)

Penobscot River at West Enfield (6 600 sq. mi.)

Androscoggin River at Rumford Falls (2 090 sq. mi.)

Mattawamkeag River at Mattawamkeag (1 500 sq. mi.) (7 years)

Kennebec River at Waterville (4 270 sq. mi.)

Presumpscot River at Sebago Lake (436 sq. mi.)

Based on climatic year, October 1 to September 30.

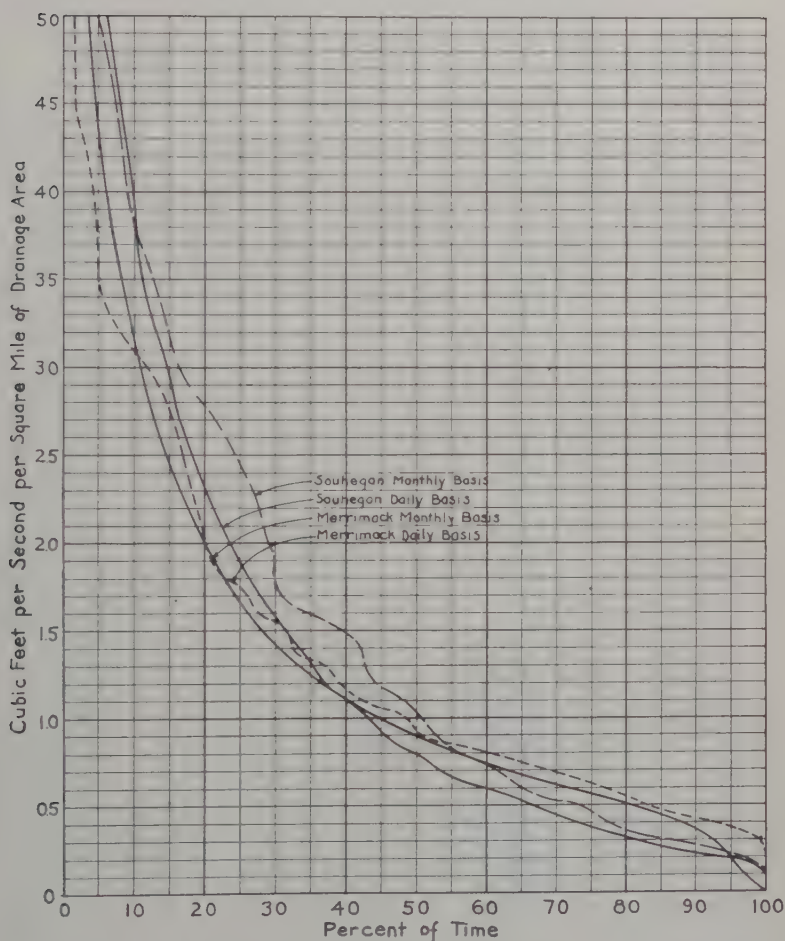


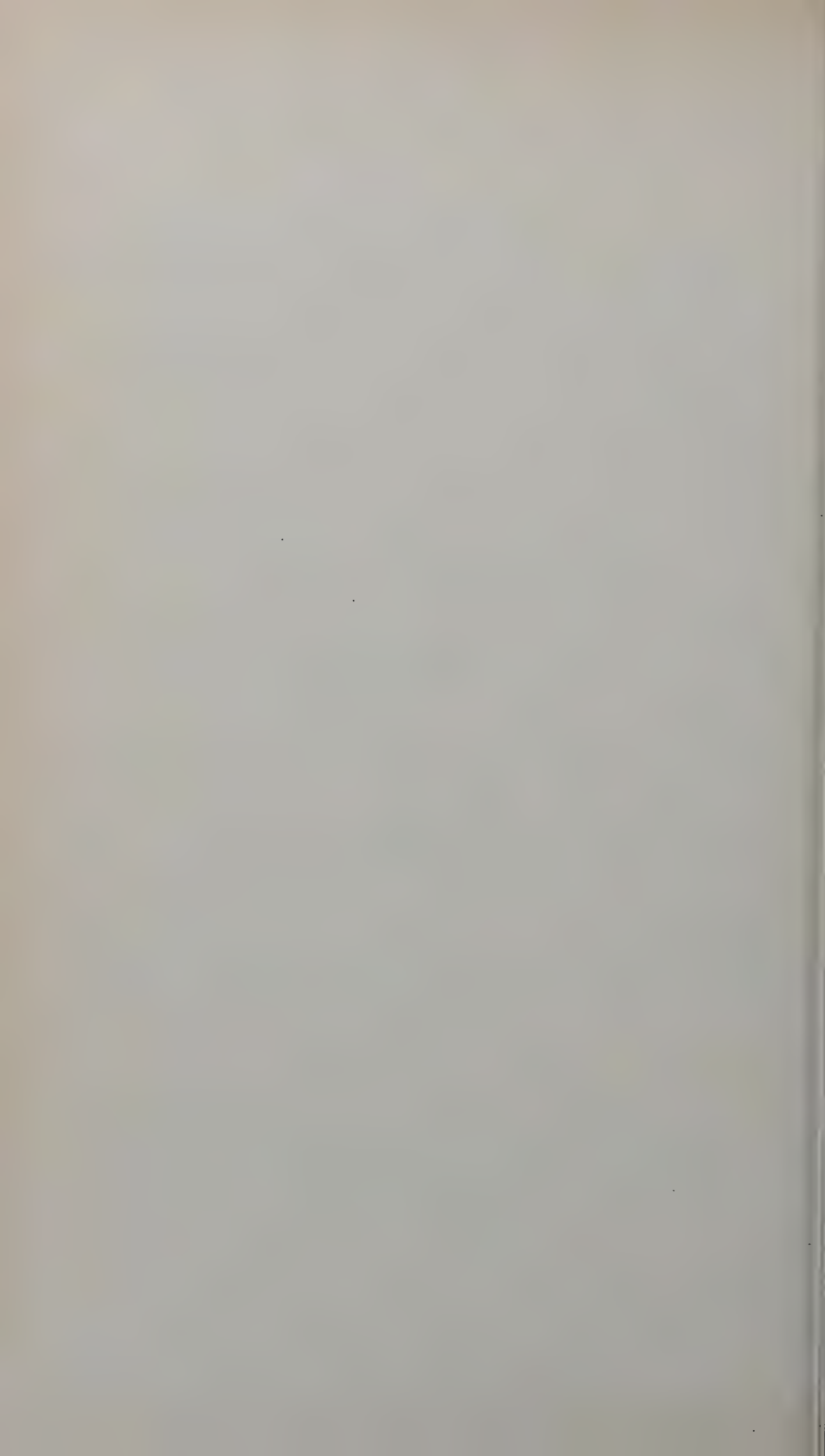
FIG. 11. — DURATION CURVES

Comparison of Daily and Monthly Basis Ten Year period  
1911-1920.

Merrimack River at Lawrence, Mass. (4 452 sq. mi. net.)

Souhegan River at Merrimack, N. H. (168 sq. mi.)

Based on climatic year, October 1 to September 30.



## MEAN ANNUAL PRECIPITATION.

*In Inches.*

(For years 1901-1920 inclusive except where otherwise noted).

|                      | Location.               | Elevation. | Precipitation            |
|----------------------|-------------------------|------------|--------------------------|
| <i>Maine</i>         |                         |            |                          |
|                      | Eastport.....           | 53         | 36.59                    |
|                      | Houlton.....            | 362        | 27.90 (1903-19)          |
|                      | Orono.....              | 129        | 39.67                    |
|                      | Millinocket.....        | 386        | 42.43                    |
|                      | Van Buren.....          | 510        | 34.98 (1903-08; 1913-18) |
|                      | Greenville.....         | 1 140      | 43.47 (1906-20)          |
|                      | Winslow.....            | 90         | 37.12                    |
|                      | Farmington.....         | 450        | 42.09                    |
|                      | Lewiston.....           | 185        | 42.21                    |
|                      | Portland.....           | 99         | 40.79                    |
|                      | Rumford Falls.....      | 505        | 39.15                    |
|                      | Cornish.....            | 778        | 46.43                    |
| <i>New Hampshire</i> |                         |            |                          |
|                      | Errol Dam.....          | 1 260      | 36.42 (1885-1907)        |
|                      | Mt. Washington.....     | 6 293      | 83.53 (1872-1886)        |
|                      | Bethlehem.....          | 1 470      | 37.19                    |
|                      | Hanover.....            | 603        | 34.76                    |
|                      | Lakeport.....           | 500        | 40.34                    |
|                      | Concord.....            | 350        | 36.07                    |
|                      | Manchester.....         | 200        | 39.40                    |
|                      | Keene.....              | 506        | 37.07                    |
| <i>Vermont</i>       |                         |            |                          |
|                      | Enosburg Falls.....     | 601        | 39.10                    |
|                      | Burlington.....         | 404        | 31.40                    |
|                      | St. Johnsbury.....      | 711        | 35.48                    |
|                      | Northfield.....         | 876        | 32.40                    |
|                      | Woodstock.....          | 700        | 37.45 (omitting 1914)    |
|                      | Wells.....              | 750        | 36.66 (1901-18)          |
|                      | Somerset.....           | 2 096      | 52.13 (1912-20)          |
| <i>Massachusetts</i> |                         |            |                          |
|                      | Lawrence.....           | 51         | 39.05                    |
|                      | Chestnut Hill.....      | 124        | 44.68                    |
|                      | Milton (Blue Hill)..... | 640        | 45.59                    |
|                      | Clinton.....            | 370        | 45.11                    |
|                      | Princeton.....          | 1 125      | 42.82                    |
|                      | Amherst.....            | 222        | 42.65                    |
|                      | Holyoke.....            | 90         | 44.60                    |
|                      | Williamstown.....       | 711        | 37.17                    |
|                      | Pittsfield.....         | 1 050      | 40.31                    |
| <i>Rhode Island</i>  |                         |            |                          |
|                      | Providence.....         | 160        | 41.95                    |
|                      | Kingston.....           | 250        | 50.46                    |
| <i>Connecticut</i>   |                         |            |                          |
|                      | Hartford.....           | 159        | 44.23                    |
|                      | New London.....         | 47         | 42.28                    |
|                      | New Haven.....          | 127        | 45.16                    |
|                      | Cornwall.....           | 1 300      | 47.57                    |

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## STREAM.

### ST. JOHN RIVER BASIN.

1. St. John R. at Fort Kent, Me.
2. St. John R. at Van Buren, Me.
3. Aroostook R. at Fort Fairfield, Me.

### ST. CROIX RIVER BASIN.

4. St. Croix R. near Woodland, Me.

### MACHIAS RIVER BASIN.

5. Machias R. at Whitneyville, Me.

### UNION RIVER BASIN.

6. West Branch of Union R. at Amherst, Me.

### PENOBSCOT RIVER BASIN.

7. West Branch of Penobscot R. at Millinocket, Me.
8. West Branch of Penobscot R. near Medway, Me.
9. Penobscot R. at West Enfield, Me.
10. East Branch of Penobscot R. at Grindstone, Me.
11. Mattawamkeag R. at Mattawamkeag, Me.
12. Piscataquis R. near Foxcroft, Me.
13. Passadumkeag R. at Lowell, Me.
14. Kenduskeag Stream near Bangor, Me.

### ST. GEORGE RIVER BASIN.

15. St. George R. at Union, Me.

### KENNEBEC RIVER BASIN.

16. Moose R. near Rockwood, Me.
17. Kennebec R. at The Forks, Me.
18. Kennebec R. at Bingham, Me.
19. Kennebec R. at North Anson, Me.
20. Kennebec R. at Waterville, Me.
21. Dead R. at The Forks, Me.
22. Sandy R. at Framington, Me.

### ANDROSCOGGIN RIVER BASIN.

23. Androscoggin R., at Errol Dam, N. H.
24. Androscoggin R. at Berlin, N. H.
25. Androscoggin R. at Rumford Falls, Me.
26. Magalloway R. at Azischohos Dam, Me.
27. Little Androscoggin R. near S. Paris, Me.

### PRESUMPCOT RIVER BASIN.

28. Presumpscot R. at outlet of Sebago Lake, Me.

### SACO RIVER BASIN.

29. Saco R. near Center Conway, N. H.
30. Saco R. at Cornish, Me.
31. Saco R. at West Buxton, Me.
32. Ossipee R. at Cornish, Me.

### MERRIMACK RIVER BASIN.

33. Pemigewasset R. at Plymouth, N. H.
34. Merrimack R. at Franklin Jct., N. H.
35. Merrimack R. at Garvins Falls, N. H.
36. Merrimack R. at Lawrence, Mass.
37. Smith R. near Bristol, N. H.

38. Contoocook R. near Elmwood, N. H.
39. Blackwater R. near Contoocook, N. H.
40. Suncook R. at North Chichester, N. H.
41. Souhegan R. at Merrimack, N. H.
42. South Branch Nashua R. at Clinton, Mass.

43. Concord R. at Lowell, Mass.

44. Sudbury R. near Framingham, Mass.

### PAWTUXET RIVER BASIN.

45. Pawtuxet R. at Fiskeville, R. I.

### THAMES RIVER BASIN.

46. Quinnebaug R. at Jewett City, Conn.

### CONNECTICUT RIVER BASIN.

47. Connecticut R. at First Lake near Pittsburg, N. H.

48. Connecticut R. at Orford, N. H.

49. Connecticut R. at Sunderland, Mass.

50. Connecticut R. at Holyoke, Mass.

51. Passumpsic R. at Pierce's Mills, Vt.

52. White R. at West Hartford, Vt.

53. Ashuelot R. at Hinsdale, N. H.

54. Millers R. near Winchendon, Mass.

55. Millers R. at Erving, Mass.

56. Sip Pond Brook near Winchendon, Mass.

57. Priest Brook near Winchendon, Mass.

58. East Branch Tully R. near Athol, Mass.

59. Moss Brook at Wendell Depot, Mass.

60. Deerfield R. at Charlemont, Mass.

61. Deerfield R. at Shelburne Falls, Mass.

62. Ware R. at Gibbs Crossing, Mass.

63. Swift R. at West Ware, Mass.

64. Quaboag R. at West Brimfield, Mass.

65. Westfield R. at Knightville, Mass.

66. Westfield R. near Westfield, Mass.

67. Middle Branch of Westfield R. at Goss Heights, Mass.

68. Westfield Little R. near Westfield, Mass.

69. Farmington R. near New Boston, Mass.

70. Hockanum R. near East Hartford, Conn.

### HOUSATONIC RIVER BASIN.

71. Housatonic R. at Great Barrington, Mass.

72. Housatonic R. at Falls Village, Conn.

73. Pomperaug R. at Bennetts Bridge, Conn.

### ST. LAWRENCE RIVER BASIN.

74. Otter Creek at Middlebury, Vt.

75. Winooski R. at Montpelier, Vt.

76. Winooski R. at Richmond, Vt.

77. Dog R. at Northfield, Vt.

78. Lamoille R. at Cady's Falls, Vt.

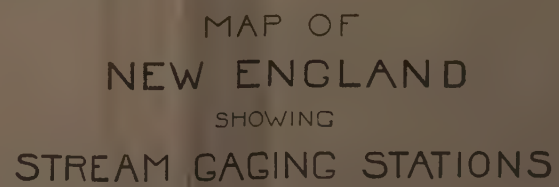
79. Lamoille R. at Johnson, Vt.

80. Green R. at Garfield, Vt.

81. Missiquoi R. near Richford, Vt.

82. Clyde R. at West Derby, Vt.





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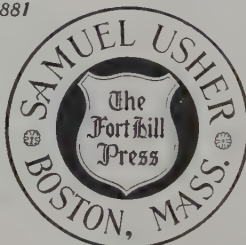
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